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SUBSCALE DEVELOPMENT OF ADVANCED ABM GRAPHITE/EPOXY COMPOSITE STRUCTURE

January 1978

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The program objective was to demonstrate by analysis fabrication, and testing of conical sections of ultra-high modulus graphite/epoxy structures that the material was applicable for utilization on future high-performance interceptors. The GY70/Fiberite 934 ultra-high modulus unidirectional tapes were used in design of the basic shell structure in the subscale development program. Laminate design was determined by analysis to meet the →

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ABSTRACT

required strength and stiffness. Titanium shims were used for reinforcement in the regions of the splice joints. Fabrication drawings were prepared for the basic conical shell and shells with reinforced joints. Static tests were conducted for ten basic shells to determine strength and stiffness and to establish a strength envelope under combined axial compression and bending loads. Two shock tests and two static tests were conducted on four shells with joint reinforcements. The shock tests were conducted to simulate stage separation shock. Test data were evaluated and the results and conclusions are given in this report.

PREFACE

This final report is prepared by Martin Marietta Aerospace, Orlando Division, for the Army Materials and Mechanics Research Center (AMMRC) Watertown, Massachusetts, under contract DAAG46-75-C-0097. This work is part of the program on Development of Hardened ABM Materials, Mr. John F. Dignam, Program Manager. The AMMRC Technical Supervisor is Mr. Lewis R. Aronin.

This report covers work conducted from 1 August 1975 through November 30, 1976. The work was performed by personnel from Martin Marietta's Aeromechanical Engineering Division. Mr. William Hurt is the program manager. Mr. Frank Koo is the task leader and Mr. Joseph Seinberg is the principal analyst. General Dynamics Corporation, Convair Division, is the fabricator of the conical shell test specimens provided to Martin Marietta as Government-Furnished Material (GFM).

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CONTENTS

LIST OF ILLUSTRATIONS

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LIST OF TABLES

1.0 SUMMARY

This report covers work performed during the period from the effective contract starting date, August 1, 1975 through November 30, 1976.

This work is part of a program that has the objective of demonstrating by analysis, fabrication, and testing of conical sections the applicability of ultra-high modulus graphite epoxy structures for utilization on future high-performance interceptor missiles.

Martin Marietta is performing detailed design and stress analysis; General Dynamics, Convair Division, is providing the fabricated test hardware as specified by the Martin Marietta design; and Martin Marietta is performing the structural testing of hardware.

An ultra-high modulus graphite fiber (GY70, manufactured by Celanese Corporation), with Fiberite 934 resin was selected for use in this program in order to meet the stiffness requirements imposed by the anticipated flight environment. The preimpregnated unidirectional tape was procured by General Dynamics in accordance with the material specification developed by Martin Marietta Corporation under a previous AMMRC contract (Reference 2). Revision B to this specification to update the requirements is included in Appendix A.

A stress analysis to determine the laminate design required for the conical shell was conducted. This shell structure represents a half-scale aft portion of a selected, typical guidance and control section of an advanced interceptor. The analysis resulted in a design having a total of 38 plies comprising the shell laminate. Twenty-two (22) plies having 0° fiber orientation relative to the missile center line are required to provide longitudinal stiffness and strength to carry the severe bending and axial loads. Twelve (12) plies having a 45° fiber orientation are required to provide the necessary torsional stiffness for proper separation between the torsional and bending frequencies needed for advanced ABM applications. A study of advanced interceptor structural frequencies was performed to establish the torsional stiffness requirements. These laminates also provide a smoother strain transition between the 0° and 90° laminae and minimize manufacturing problems. Four (4) plies having 90° fiber orientation are required to carry the hoop loads acting on the structure. A summary of the laminate design is given in Table 1-I.

Table 1-I. Laminate Design Summary

Number of Plies	Fiber Orientation, Degrees
22	0
6	+45
6	-45
4	90

Layup Sequence:

$[0_2|+45|90|-45|90|+45|0_3|-45|0_3|+45|0_2|-45|0]_s$

Composite Properties:

$E_x = 26.7 \times 10^6$ psi $\qquad \nu_{yx} = 0.12$

$E_y = 8.1 \times 10^6$ psi $\qquad \nu_{xy} = 0.40$

$G_{xy} = 3.8 \times 10^6$ psi

This layup sequence is specified by the fabrication drawing (48125, Revision D) shown in Appendix B.

It is necessary to affix end support rings to the frusta so that test loads may be applied to the structure. An evaluation of test support ring materials and bonding agents was conducted to determine the desired materials for this application. Results show that potted fiberglass materials cannot develop adequate bonding strength for the test loading. Aluminum rings bonded to the GY70 shell with EA 9309 adhesive with controlled bond line thickness can develop the bond strength required for the structural testing of the composite shell. The support ring assembly drawing, 48130, is included in Appendix B.

A drill fixture was designed and fabricated at Martin Marietta for drilling bolt hole patterns in the aluminum rings. After completing the drilling of the aluminum rings for the five shells, the fixture was shipped to General Dynamics for their use in the alignment of aluminum rings during the bonding process.

Ten half-scale simple conical shells with aluminum end rings were subjected to structural loading tests to determine the load carrying capability of the GY70/Fiberite 934 shells under various combinations of loads. The test results are summarized in Table 1-II and Figure 1-1. These results verify the validity of the analytical procedures which were used to design the shell laminate and the manufacturing processes used to fabricate the conical shell. Good correlation with analytical prediction of load carrying capability was obtained. It can therefore be concluded that a conical shell laminate can be designed and fabricated using GY70/ Fiberite 934 ultra high modulus composite material, based on load and boundary conditions for the Advanced Terminal Interceptor (ATI), with the resulting structure having predictable load carrying capability.

A joint reinforcement design and analysis was also conducted at Martin Marietta. Three design candidates which require titanium shims for reinforcements were recommended for testing. Detailed analysis revealed that non-metal reinforcement designs require excessively thick sections due to the low bearing strengths of the materials. Evaluation of the three titanium reinforcement concepts with respect to design, fabrication and testing will determine the best reinforcement concept for the splice joints. The three titanium reinforcement designs are shown in Appendix C.

Table 1-II. Summary of Test Results

TEST	CONICAL SHELL NUMBER	LOADING CONDITION	FAILURE LOAD		TYPE OF FAILURE
			TEST	ANALYSIS	
1	004	COMPRESSION	160000 LB (AXIAL COMP)	166000 LB (AXIAL COMP)	OVERALL COMPRESSION FAILURE AT SMALL END
2	001	SHEAR/BENDING	20000 LB (SHEAR)	31300 LB (SHEAR)	LOCALIZED INTERLAMINAR SHEAR FAILURE AT LARGE END
3	002	COMBINED LOAD-SIMULTANEOUS	180% DESIGN LIMIT LOADS (DLL)	158% DLL	OVERALL COMPRESSION FAILURE AT LARGE END
4	003	COMBINED LOAD-CONSTANT COMPRESSION	53334 LB AXIAL COMP + 180% DLL FOR OTHER LOADS*	53334 LB AXIAL COMP + 139% DLL FOR OTHER LOADS*	OVERALL COMPRESSION FAILURE AT SMALL END
5	005	COMBINED LOAD-CONSTANT BENDING MOMENT AT LARGE END	64662 IN-LB BENDING MOMENT AT LARGE END + 540% AXIAL COMP DLL	64662 IN-LB BENDING MOMENT +700% AXIAL COMP DLL	OVERALL COMPRESSION FAILURE AT SMALL END
6	006	COMPRESSION	180000 LB (AXIAL COMP)	166000 LB (AXIAL COMP)	OVERALL COMPRESSION FAILURE AT SMALL END
7	007	COMBINED LOAD-SIMULTANEOUS	200% DLL	158% DLL	COMPRESSION FAILURE AT LARGE END
8	008	COMBINED LOAD-CONSTANT COMPRESSION	80,000 LB AXIAL COMP + 150% DLL FOR OTHER LOADS*	80,000 LB AXIAL COMP + 104% DLL FOR OTHER LOADS*	COMPRESSION FAILURE AT SMALL END
9	009	COMBINED LOAD-CONSTANT BENDING MOMENT AT LARGE END	64662 IN-LB BENDING MOMENT AT LARGE END + 720% AXIAL COMP DLL	64662 IN-LB BENDING MOMENT + 700% AXIAL COMP DLL	COMPRESSION FAILURE AT SMALL END
10	010	COMBINED LOAD-CONSTANT COMPRESSION	15000 LB AXIAL COMP + 170% DLL FOR OTHER LOADS*	15000 LB AXIAL COMP + 176% DLL FOR OTHER LOADS*	LOCALIZED INTERLAMINAR SHEAR AND BOND FAILURE AT LARGE END

*OTHER LOADS ARE BENDING MOMENT, SHEAR AND LATERAL PRESSURE LOADS.

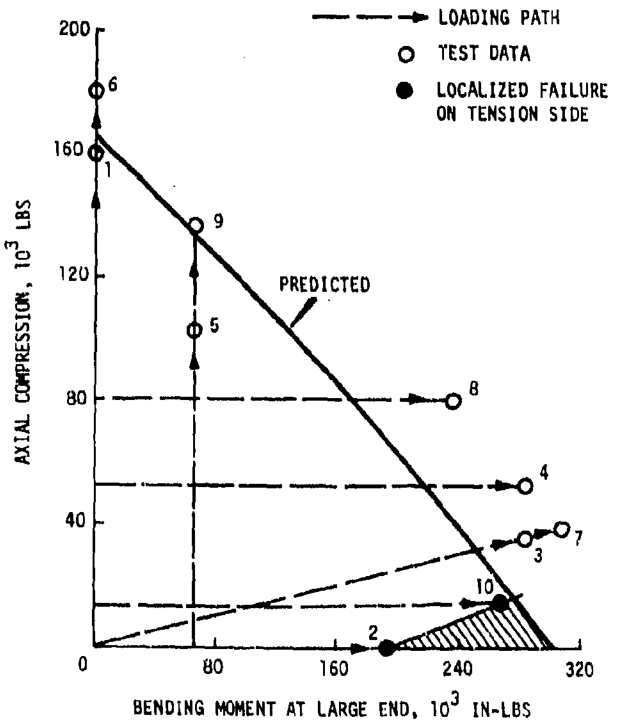


Figure 1-1. Load Interaction Diagram

Four reinforced frusta were fabricated at General Dynamics in accordance with Detail B, Design 1, of Drawing 48126 (Appendix C). The reinforced section consists of 22 layers of 0° fibers, 12 layers of ±45° fibers, 4 layers of 90° fibers and 11 layers of titanium shims as reinforcements. After the first two units had been fabricated, a revision was made to the layup sequence to facilitate the fabrication and strengthen the surface layers. The revision is shown in 48126B (Appendix C). The following layup sequence was used for fabricating the first two units (01R and 02R):

$$[0/Ti/0/45/90/-45/Ti/90/45/0_2/Ti/0/-45/0_2/Ti/0/45/0/Ti/0/-45/0/\overline{Ti}]_s$$

Units 3 and 4 (03R and 04R) were fabricated in addordance with the following revised layup sequence that conforms to Drawing 48126B shown in Appendix C.

$$[0_2/45/Ti/90/-45/Ti/90/45/0_2/Ti/0/-45/0_2/Ti/0/45/0/Ti/0/-45/0/\overline{Ti}]_s$$

Shock tests were conducted on units 01R and 02R to simulate the stage separation shock. Fifteen runs were made on each unit, from low to high level shocks in increments, until the maximum shock corresponding to stage separation was reached. Both units withstood the maximum shock level and suffered minor surface cracks extending from the countersunk bolt holes to the edge of the frustra. These cracks are considered minimal damage and can be alleviated by the revised layup sequence.

Units 03R and 04R were subjected to static load tests to evaluate the load carrying capability of the reinforced joints. Unit 03R was loaded in combined loading simulating the design condition; unit 04R was loaded by a single lateral load in a shear/bending case, subjecting the joint to equal tension and compression loads. Unit 03R failed at 200% Design Limit Load (DLL), and failure occurred in the basic shell region. Unit 04R failed at 34,000 pounds at the small end of the frustrum.

It is significant to note that in both tests the joints are stronger than the basic shells and are capable of plastic deformation to increase the ultimate load carrying capability of the reinforced joints.

The test results are summarized in Table 1-III.

Table 1-III. Summary of Test Results Joint Reinforcement Frusta

Test Number	Unit	Test Condition	Loading		Type of Failure
			Test	Design	
1A	01R	Axial Shock	41,000g's* Peak	42,000g's Peak	Surface crack developed at 52,000g's at one bolt hole**
2A	02R	Axial Shock	37,000g's*	42,000g's	Surface crack developed at 22,000g's at one bolt hole**
3A	03R	Combined Load-Simultaneous	200% Design Limited Load (DLL)	162% DLL	Compressive Failure in the shell. Bolt holes elongated
4A	04R	Shear/Bending	34,000 lbs.	30,000 lbs.	Failure at small end bolt holes elongated

*Maximum peak g's response attainable from SM-100 shock machine for the two particular tests.
**The surface cracks through the first layer of titanium shim had no significant impact on joint strength.

2.0 INTRODUCTION

2.1 Background

Structural requirements for advanced interceptors have continually shown the need for light-weight, high-modulus materials. System studies for BMDATC performed by Martin Marietta under Contracts DAAHC-60-72-C-0022 (Reference 3) and DASG-60-75-C-0043 (Reference 4) highlighted the advantages of ultra high modulus graphite epoxy and beryllium structures. The results of these studies have shown that ultra high modulus graphite epoxy primary structures will provide a significant launch weight reduction over more conventional materials. These results are shown in Figure 2-1. This relationship was developed on the basis that all structural frequencies should be proportionally above the control system bandwidth. This criterion establishes that a first structural bending mode frequency above 70 Hz at second stage ignition is required. When this requirement is imposed on structural design for advanced ABM loading condition, both the ultra high modulus graphite epoxy and beryllium offer significant weight savings over aluminum and high strength graphite epoxy.

Martin Marietta has performed material trade studies on high strength and high modulus graphite fibers and epoxy resin systems under AMMRC contract DAAG46-75-C-0052 (Reference 1). Fabrication variables were evaluated in the fabrication of cylindrical shells. Under another AMMRC contract in the development of graphite/epoxy composite for interceptor structural application (Reference 2), a material specification and a process control specification were developed. Laminate ply angle testing was conducted at room temperature and 360°F in the same contract.

The primary objective of the Subscale Conical Shell Development program delineated herein is to demonstrate the feasibility of ultra high modulus graphite/epoxy structures for advanced ABM applications. The secondary objectives are: a) to experimentally verify design techniques for laminated conical shells fabricated from unidirectional prepreg tapes and b) to develop reinforcement designs for joints, cut-outs and attachments in a low strain composite material under shock loadings.

As discussed in Reference 3, a representative missile was chosen from a series of missiles evaluated in Terminal Interceptor studies. The guidance and control section was chosen as a representative structural section because it contained design features such as splice joints, support rings, cut-outs and basic shell, which would need verification in a graphite/epoxy structure.

GY70 was selected as the ultra high modulus graphite fiber for the Subscale Conical Shell Development Program because of cost advantage and availability. GY70 is a product of Celanese Corporation of Summit, New Jersey. The preimpregnated unidirectional tape, GY70/Fiberite 934, used in the fabrication of the conical shells is purchased from Fiberite Corporation of Winona, Minnesota.

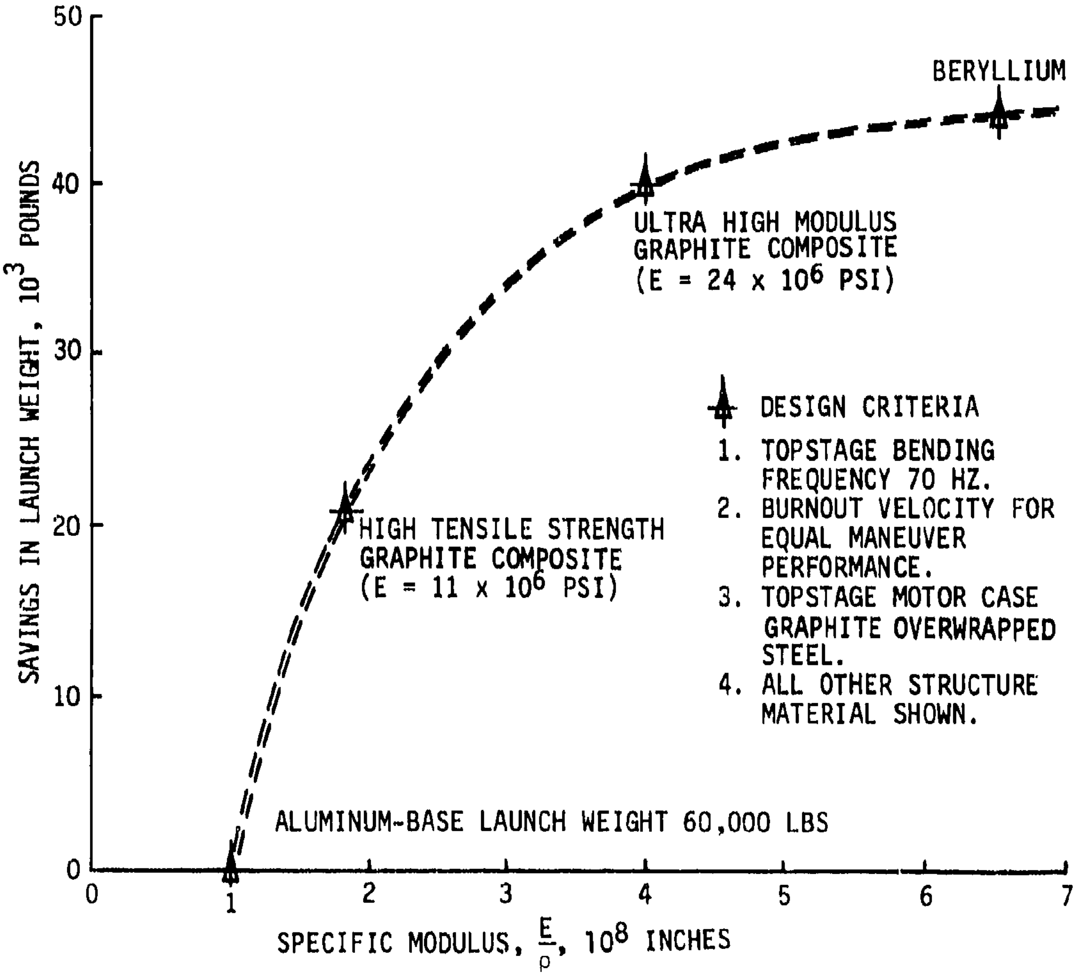


Figure 2-1. Effect on Launch Weight for Stiffness Critical Design of Advanced Interceptors

2.2 Technical Approach

The technical effort required by this contract consisted of the following tasks:

2.2.1 Conical Shell Design

a) Design of a half-scale cone frustum representing the aft section of a typical advanced ABM guidance and control section, Figure 2-2.

b) Definition of design loads and stiffness requirements.

c) Determination by analysis of a layering sequence and fiber orientation of each layer required to meet the design conditions.

d) Preparation of engineering drawings for the fabrication of conical sections by Convair Division of General Dynamics, San Diego, California.

2.2.2 Testing of Subscale Conical Section

a) Axial compression, bending and combined loads testing to obtain strength and stiffness data on 10 subscale conical frusta fabricated by General Dynamics. Fabrication of frusta described in this report was accomplished by General Dynamics under AMMRC contract DAAG46-76-C-0008.

b) Determination of ultimate loads, effective modulus, deformation patterns and failure modes for each condition.

2.2.3 Test Data Analysis and Correlation

a) Analytical predictions of performance for each of the loading conditions of the specimens to compare with test data.

2.2.4 Shell Reinforcement Design

a) Development of three (3) reinforcement designs for splice joints of the advanced ABM structural sections.

b) Determination by analysis of reinforcement thickness required, considering both strength and stiffness requirements in the overall structural joint design.

c) Preparation of engineering drawings for fabrication of conical shells with reinforced splice joints by General Dynamics.

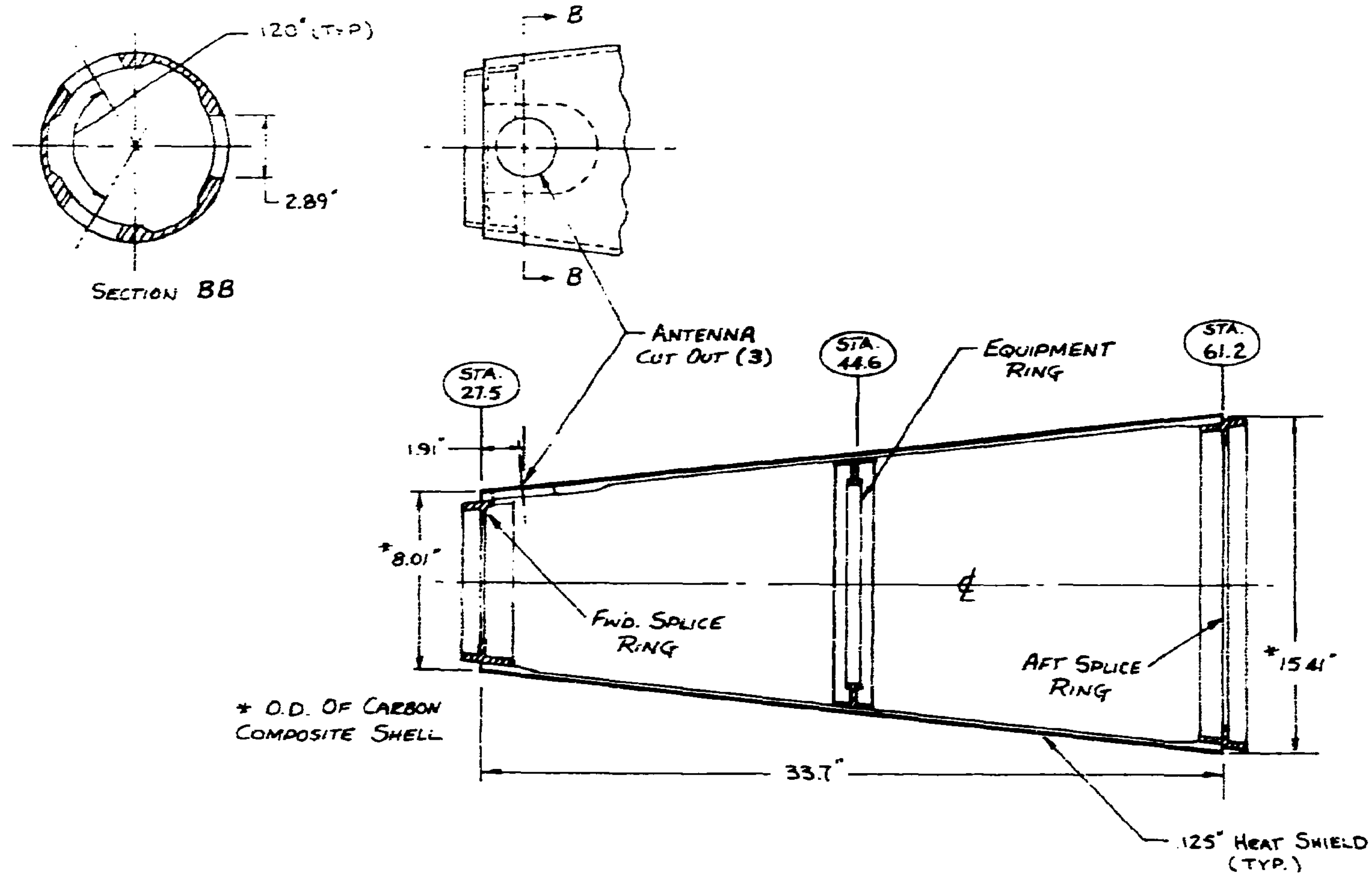


Figure 2-2. Guidance and Control Section Structural Configuration

2.2.5 Testing of Joint Reinforcement Shells

a) Shock testing to evaluate the load carrying capabilities of 2 reinforced shells of Design 1 (Appendix C) under shock loading.

b) Bending and combined loads testing to obtain strength and stiffness data on 2 reinforced shells.

c) Determination of shock levels and magnitudes of strains imposed on the reinforced shells during shock testing.

d) Comparison of analytical prediction of performance for each of the static loading conditions with test data.

3.0 CONICAL SHELL DESIGN

3.1 Laminate Sequence Design

Analyses were conducted to determine a GY70/Fiberite 934 laminate design for a half scale model of the conical aft portion of the ATI Guidance and Control Section to meet the stress requirements resulting from axial load, shear load, bending moment and external pressure. The critical load condition, shown in Figure 3-1, was established for the full size G&C section. For the half scale section, the loads were scaled down based on the criterion that the resultant stresses remain the same when the shell dimensions are reduced from full scale to half scale. Scale factors for the loads in Figure 3.1 are calculated for axial load, bending moment and shear based on the following stress equations. For these equations subscript 1 represents parameters on the full scale model and subscript 2 represents parameters on the half scale model.

Axial Stress, $\sigma_a = \frac{P}{A} = \frac{P_1}{2\pi r_1 t_1} = \frac{P_2}{2\pi r_2 t_2}$ where $r_2 = 1/2\ r_1$ = radius
$t_2 = 1/2\ t_1$ = thickness

Axial Load, $P_2 = \frac{P_1(2\pi r_2 t_2)}{2\pi r_1 t_1} = 1/4\ P_1$

Bending Stress, $\sigma_{b_{max}} = \frac{Mr}{I} = \frac{M_1 r_1}{\pi r_1^3 t_1} = \frac{M_2 r_2}{\pi r_2^3 t_2}$

Bending Moment, $M_2 = \frac{M_1 r_1 (\pi r_2^3 t_2)}{(\pi r_1^3 t_1) r_2} = 1/8\ M_1$

Shear Stress, $\sigma_{s_{max}} = \frac{VQ}{It} = \frac{V_1(\pi r_1 t_1)(\frac{2r_1}{\pi})}{\pi r_1^3 t_1^2} = \frac{V_2(\pi r_2 t_2)(\frac{2r_2}{\pi})}{\pi r_2^3 t_2^2}$

Shear Load, $V_2 = \frac{V_1 r_1^2 t_1 (\pi r_2^3 t_2^2)}{r_2^2 t_2 (\pi r_1^3 t_1^2)} = 1/4\ V_1$

Preliminary analysis has established that buckling is not critical for the conical shell geometry under consideration. Therefore, the shell design is based on strength and stiffness (bending frequency) requirements.

Laminate designs are required to be symmetrical and balanced to minimize induced bending and cross coupling effects. Preliminary laminate designs were analyzed for the scaled down loads using the KLIGER code which is a point stress laminate analysis computer code (Reference 5). The output of this code yields lamina stresses and strains, equivalent elastic and shear modulii for the laminate designs and buckling allowables. The laminae configurations analyzed are given in Table 3-I.

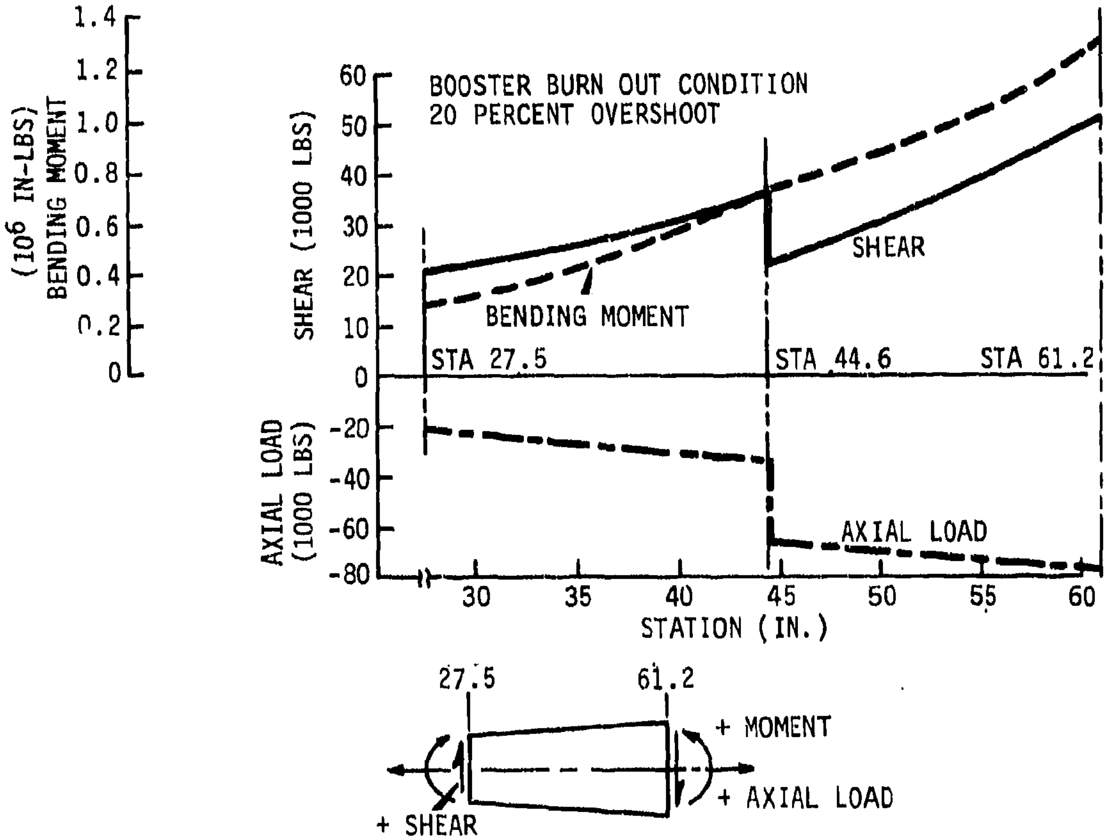


Figure 3-1. Limit Critical Overall Load Condition for Guidance and Control Section

NOTE: For 1/2 scale
Divide Shear by 4
Divide Axial Load by 4
Divide Bending Moment by 8

Table 3-I. Laminate Design Progression for GY70/Fiberite 934 - Half Scale Frustum

Configuration	Layup Sequence	Ply 0°	Ply 45°	Ply 90°	Analysis Codes	M.S.*	Remarks
I	$[90_3 \mid +45 \mid 0_4 \mid -45 \mid 0_4 \mid +45 \mid 0_3 \mid -45]_s$	22	8	6	KLIGER	-.05	Preliminary design based on design charts in Advanced Composites Design Guide
II	$[90_3 \mid +45 \mid 0_4 \mid -45_2 \mid 0_4 \mid +45_2 \mid 0_3 \mid -45]_s$	22	12	6	KLIGER	+.26	Add 4 45's to improve the M.S.
III	$[90_2 \mid +45 \mid 0_4 \mid -45_2 \mid 0_4 \mid +45_2 \mid 0_3 \mid -45]_s$	22	12	4	SLADE KLIGER	+.39	Remove 2 90's to reduce thickness. Revise shell geometry and loads.
IV	$[0_2 \mid +45 \mid 90_2 \mid -45 \mid 0_2 \mid +45 \mid 0_2 \mid -45 \mid 0_2 \mid +45 \mid 0_2 \mid -45 \mid 0]_s$	22	12	4	SLADE KLIGER	>+.39	Regroup to minimize the stacking of 0's. Lay 0's at outside surfaces for shear transfer
V	$[0 \mid \pm 45 \mid 90_2 \mid +45 \mid 0 \mid -45 \mid 0 \mid +45 \mid 0 \mid -45 \mid 0_7]_s$	22	12	4	SLADE KLIGER	+.26	General Dynamics' initial recommendation
VI	$[0_2 \mid +45 \mid 90 \mid -45 \mid 90 \mid +45 \mid 0_3 \mid -45 \mid 0_3 \mid +45 \mid 0_2 \mid -45 \mid 0]_s$	22	12	4	SLADE KLIGER	+.67	Final layup concurred by Martin and General Dynamics

$$* \text{ M.S. (Margin of Safety)} = \frac{\text{Allowable Material Strength}}{\text{Limit Stress X Factor of Safety}} - 1$$

Limit Stress is stress computed from limit loads. Factor of safety is taken as 1.5.

The axial load, shear and bending moment diagrams shown in Figure 3-1 are applicable for the full scale ATI Guidance and Control section from station 27.5 to station 61.2. The half scale conical shell evaluated in this task represents the aft section of the G&C section (station 44.6 to station 61.2), and the design loads are scaled down from those in Figure 3-1 such that the resulting stress levels in the half-scale shell are the same as those in the full scale. The scale factor for each of the loadings was derived on page 12.

After completing the preliminary laminate design using the KLIGER code, a finite element model was developed for the half scale conical shell in order to determine fixed end effects and to locate the critical stress elements. The shell wall was considered to be of a homogeneous material with thickness equivalent to laminate Configuration III. The finite element model was developed for the SLADE program (Reference 6) a finite element program for the static analyses of shells which uses curved shell elements. The finite element model for the conical shell is shown in Figure 3-2. The loads applied to the model are given in Figure 3-3. The stress resultants on the critical stress elements were then used as inputs to the KLIGER code to complete the analysis cycle. The meridian stress distributions along the length of the shell are plotted in Figure 3-4. The critical stress elements are at the fixed end as shown in the plots. For this analysis an option was used in the KLIGER code allowing for stress resultants on an element to be input instead of overall structural loads. In this way the effect of the fixed end on the laminate design could be analyzed. The maximum stress and strain for each of the elements were computed. Figure 3-5 gives the stresses in the direction of the fibers in each layer of the laminate as computed from KLIGER code. The results were initially based on a laminae sequence described in notation form as: $[90_2|45|0_4|-45_2|0_4|45_2|0_3|-45]_s$. Discussion with personnel from General Dynamics led to the evaluation of other laminae configurations for fabrication considerations. The final layup agreed upon by Martin Marietta and General Dynamics was: $[0_2|45|90|-45|90|45|0_3|-45|0_3|45|0_2|-45|0]_s$. The minimum margin of safety of this laminae configuration is 0.67 based on an individual lamina thickness of 0.0065 in.

In addition to the calculations of stresses and strains in the laminae for each layup sequence, the shell stiffness (EI) was also computed to assure that the stiffness requirement was satisfied. The required EI at the aft station of the G&C section is 11.7 x 10^9 lb-in^2 for the full size structure. For the half scale structure, the required EI is equal to 1/16 of the value of the full size structure or 0.731 x 10^9 lb-in^2, since I equals r^3t and E is assumed to be independent of size. All laminae designs investigated have met the stiffness requirement. The final configuration (configuration VI of Table 3-I) has an EI of 1.076 x 10^9 lb-in^2 or 47% above the requirement based on an individual lamina thickness of 0.0065 in.

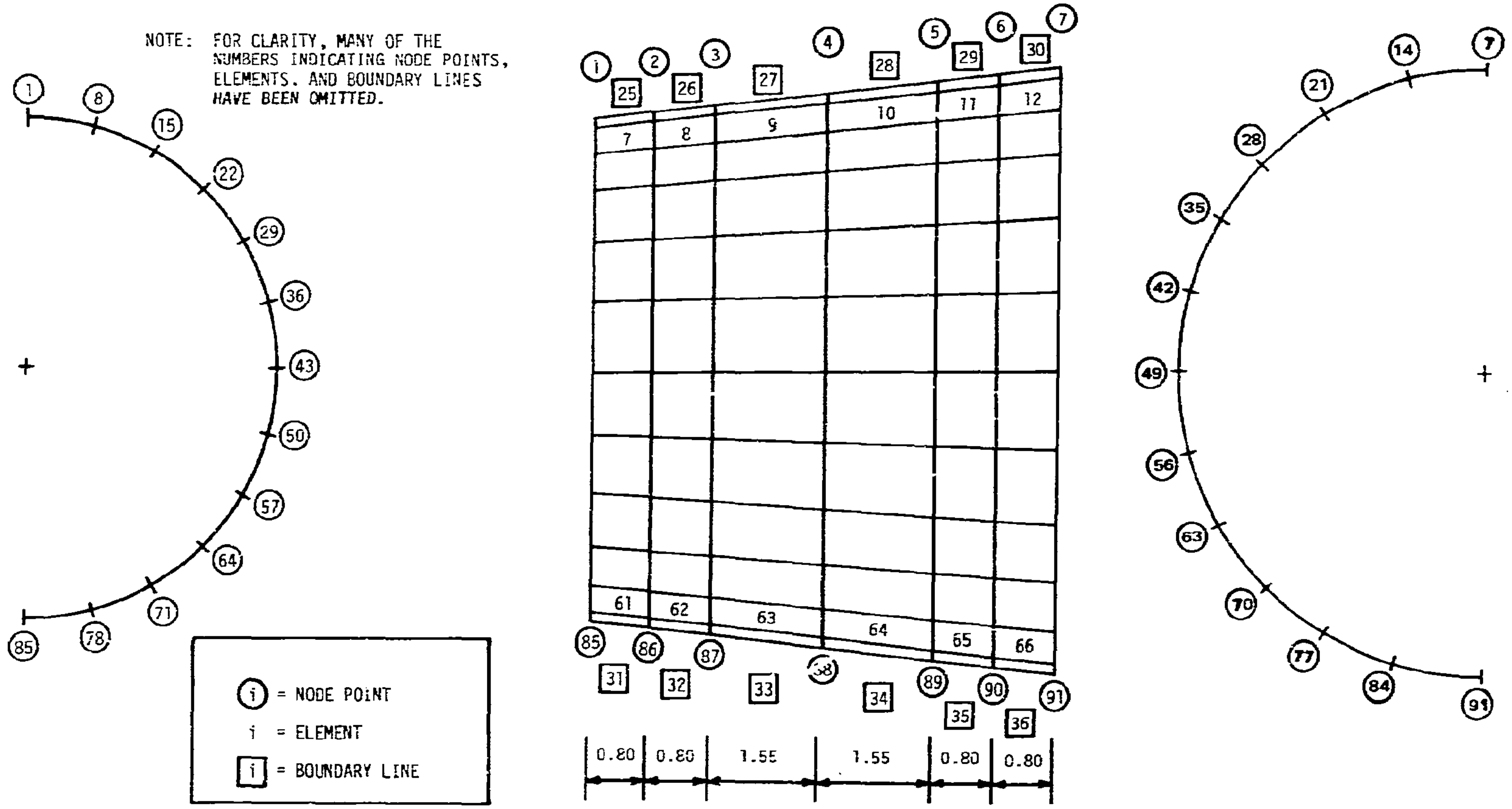
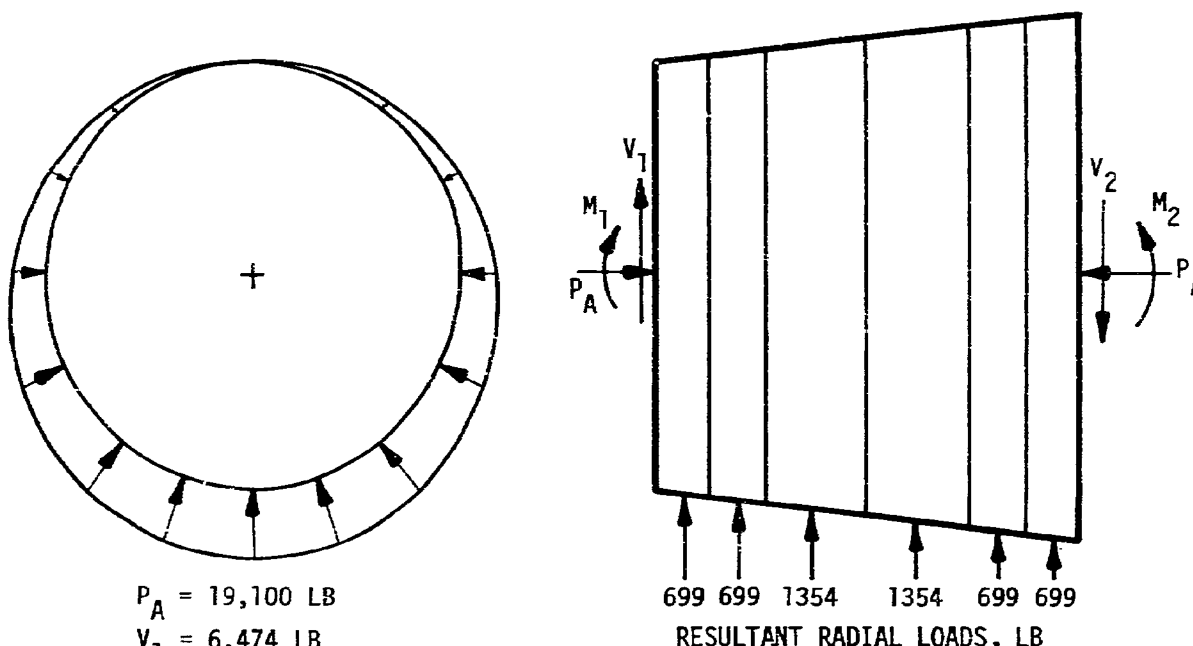


Figure 3-2. SLADE Finite Element Model



P_A = 19,100 LB
V_1 = 6,474 LB
M_1 = 99,837 IN-LB
V_2 = 11,978 LB
M_2 = 157,961 IN-LB

Figure 3-3. Loads on Finite Element Model

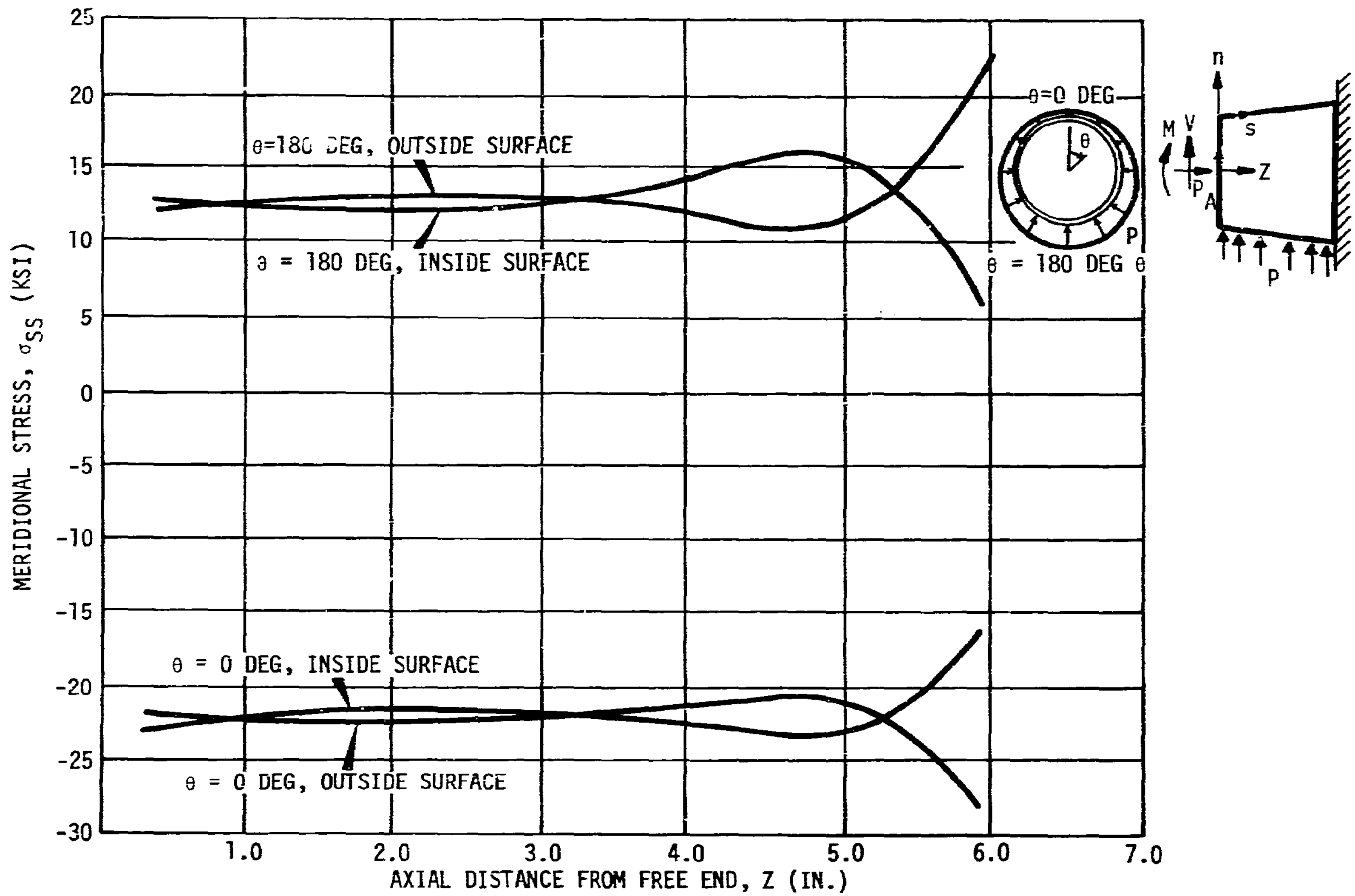


Figure 3-4. GY 70/934 G&C Test Section Meridional Stress versus Axial Distance SLADE Output

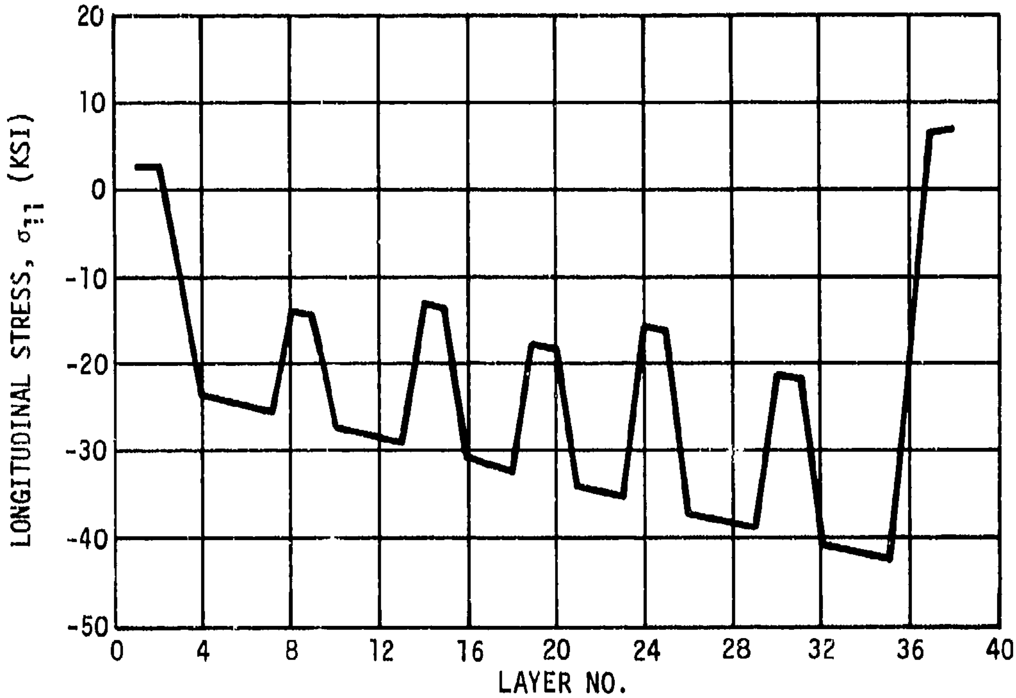


Figure 3-5. GY 70/934 G&C Test Section - Laminate Design VI - Longitudinal Stress versus Layer Number

3.2 Torsional and Bending Frequency Analysis

A study was conducted to establish the torsional natural frequencies of the missile structure and to compare these with the bending frequencies to assure that torsional-bending coupling would not be a problem.

Torsional and bending frequencies were calculated using the Jacobi Rotational techniques. Two graphite epoxy laminae designs were investigated; a design with 45° laminae, $0_{22}/45_{12}/90_4$ (Drawing 48125), and a design without 45° laminae, $0_{34}/45_0/90_4$. It was required that all structural frequencies should be above the control system frequency and should thus be above 70 Hz for second stage ignition. Also, the fundamental torsional frequency should be widely separated from the first bending frequency.

The results are summarized in terms of frequency in Table 3-II. The frequencies shown in Table 3-II do not include degradation due to structural joints. An approximate reduction of 10% can be expected in bending frequency and a smaller reduction can be expected in torsional frequency due to the joints. Good design practice dictates that a factor of 3.0 to 4.0 is required for the separation of torsional and bending frequencies in order to prevent roll-pitch coupling in flight. First mode torsion-to-bending frequency ratios of 3.5 and 1.8 were calculated for the laminae designs with 45° layers and without 45° layers respectively. Therefore, from torsional stiffness consideration 45° laminae are required in the design of the GY70/epoxy conical shell for ATI application.

Table 3-II ATI Missile Structural Frequencies

GY70/Epoxy Laminate	Torsion Frequency (Hz)			Bending Frequency (Hz)		
	1st	2nd	3rd	1st	2nd	3rd
$0_{22}/45_{12}/90_4$	274	397	604	78	178	399
$0_{34}/45_0/90_4$	151	183	303	83	200	419
Objective	280			70		

3.3 Support Ring Design For Test Loading of Frusta

Structural testing of simple conical shells without the advantage of built-in fixture attachment means presents the problem of design for shear transmission of test loads into the shell ends. A form of bonded mounting rings which could withstand the high test loads was sought. In the design and analysis of the mounting rings for the graphite epoxy shell, it is required that the strength of the ring material and the bond strength between the ring and the shell be known. To determine the strength of the fiberglass rings a simple test specimen was fabricated and tested as shown in Figure 3-6. To develop the maximum design load in the fiberglass ring attachments, an applied load of 20,000 lbs. is required, and a 30,000 lbs. load will provide a 50% margin of safety. The specimen failed at an applied load of 18,000 lbs. with bond line failure at the aluminum and fiberglass interface. The maximum bond line shear stress at failure was 1,290 psi. The required bond line shear stress is 2,150 psi.

A series of material tests was initiated for the purpose of finding a ring material and adhesive which would provide a sufficient margin for the test loading. Two types of double shear specimens were fabricated to simulate the shell to ring interface. The first series had fiberglass blocks potted on 0.25 in. thick aluminum plates. The second series used graphite epoxy flat laminates (Thornel 300/Fiberite 934) bonded to aluminum blocks or to potted epoxy blocks. The configuration of the specimens for both test series is shown in Figure 3-7. The specimens were loaded in the Instron Testing machine to failure, and failure loads were recorded.

The average shear stresses at failure were computed. The test results are summarized in Table 3-III. In the first series, the potted fiberglass blocks exhibited adhesive failure at the bond line. The shear stress levels at failure were inadequate for the loads applied in the testing of the graphite epoxy shell. Therefore, use of potted fiberglass rings was not considered a viable technique. In the second series, all specimens failed in interlaminar shear of the graphite epoxy laminates. The failure stress was considerably higher with the aluminum blocks than with the potted epoxy blocks because the deformation of the low modulus epoxy blocks induced tension in addition to shear in the laminates. To evaluate the orientation effect of the fibers which are bonded to the blocks, six (6) specimens were made with surface fibers parallel to the loading and another six (6) specimens were made with surface fibers perpendicular to the loading. The specimens with surface fibers parallel to the loading failed at higher loads than the ones perpendicular to the loading. The limited number of test specimens do not give quantitative design values, however, they do show the trend in the selection of ring materials and adhesive. The results of the material testing support the use of aluminum rings bonded to the graphite shell with the fibers of the bonded surfaces parallel to the direction of maximum shear.

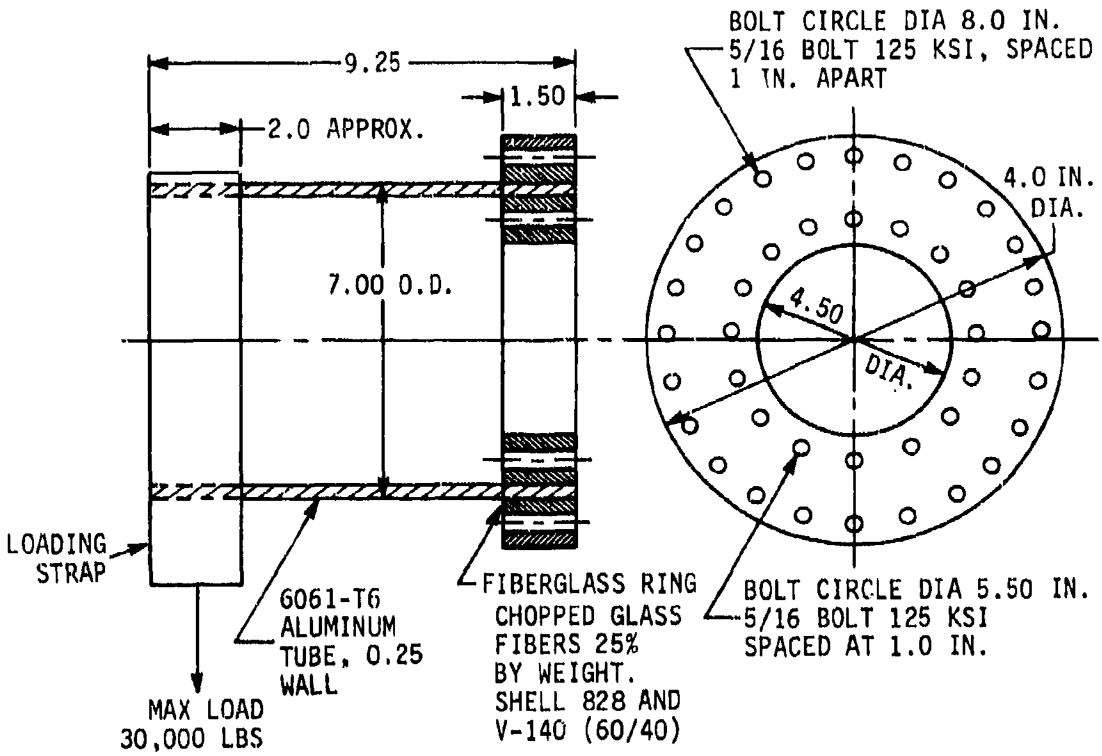


Figure 3-6. Fiberglass Ring and Strength Test Specimen

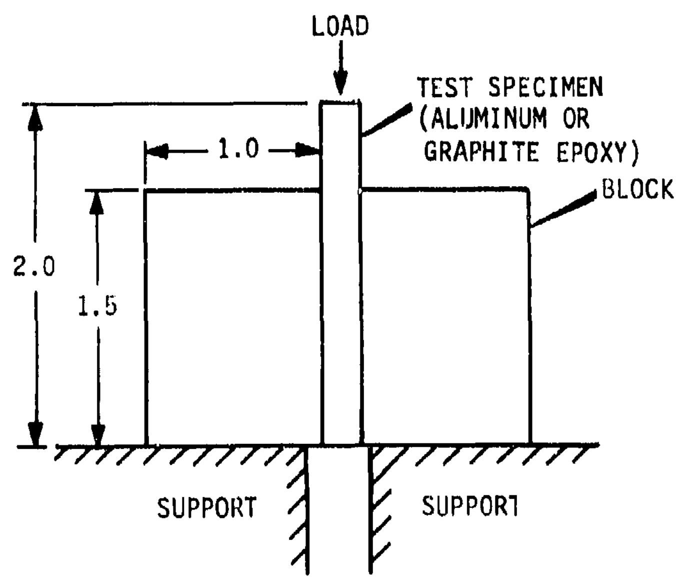


Figure 3-7. Material Test Specimen Configuration

Table 3-III Testing of Mounting Ring Materials
And Bonding Agents

	Material		Adhesive	No.	Range Shear, psi	Failure Mode
Bonded to Alum Plate	815/V140 10% Fiberglass	100/75	Self-Bonding	4	1,870 - 2,020	Bondline
	828/V140 10% Fiberglass	100/75	Self-Bonding	4	833 - 1,315	Bondline
	828/Z 10% Fiberglass	100/75	Self-Bonding	4	1,300 - 1,420	Bondline
	828/V140 25% Fiberglass	50/50	Self-Bonding	4	1,670 - 1,900	Bondline
Bonded to T300/Fiberite 934 Laminate	6061-T6	Alum	EA 934 (Bond Fibers parallel to load)	4	3,500 - 4,570	Interlaminar Graphite/Epoxy
	6061-T6	Alum	EA 934 (Bond Fibers perpendicular to load)	4	2,200 - 3,620	Interlaminar Graphite/Epoxy
	EA 9309		Self Bonding (Fibers parallel to load)	2	1,235 - 1,650	Interlaminar Graphite/Epoxy
	EA 9309		Self Bonding (Fibers perpendicular to load)	2	1,220 - 1,540	Interlaminar Graphite/Epoxy

A survey was conducted to determine an adhesive with adequate bond strength to transfer the maximum test loads from the conical graphite shell to the aluminum support rings. Hysol adhesive EA 9309 was selected since it has superior bond strength when compared to other adhesives considered. A comparison of vendor strength data on EA 934 and EA 9309 shows the following:

	Shear, psi	Peel, psi
EA 934	3000	2
EA 9309	4750	39

Two tests were then conducted to confirm the adequacy of EA 9309 as the bonding agent between the shell and support rings for the purposes of structural testing. The test setup, consisting of a 0.250 inch thick aluminum cylinder bonded to an aluminum plate with a 0.125 inch thick, 0.75 inch overlap bondline of EA 9309, is shown in Figure 3-8. The results of the two tests are summarized in Table 3-IV and indicate that EA 9309 has adequate bond strength to transfer the maximum test loads. The failure at the bonded joint on the second specimen is shown in Figure 3-9.

To further investigate the support ring system, a finite element model was developed for a preliminary analysis of a conical GY70/934 shell bonded to aluminum support rings using EA 9309 adhesive. The analysis was conducted to determine axial stresses in the GY70 laminae in the region of the support rings as well as to determine load transfer and shear stress distribution between adjacent GY70 laminae and in the adhesive layer between the shell and the rings. The analysis was conducted for a uniform axial tensile load using TEXGAP, the Texas Institute for Computational Mechanics Grain Analysis Program (Reference 7). The results indicated that there are locally high stress levels in the region of load transfer between the graphite surface layers and the aluminum support rings. However based on this analysis, it was determined that the structure is capable of withstanding the ultimate design loading condition.

On the basis of the above mentioned test and analytical determinations, a support ring system consisting of aluminum rings bonded to the inside and outside surfaces of the graphite shell at both ends with EA 9309 was designed and implemented for the initial test series.

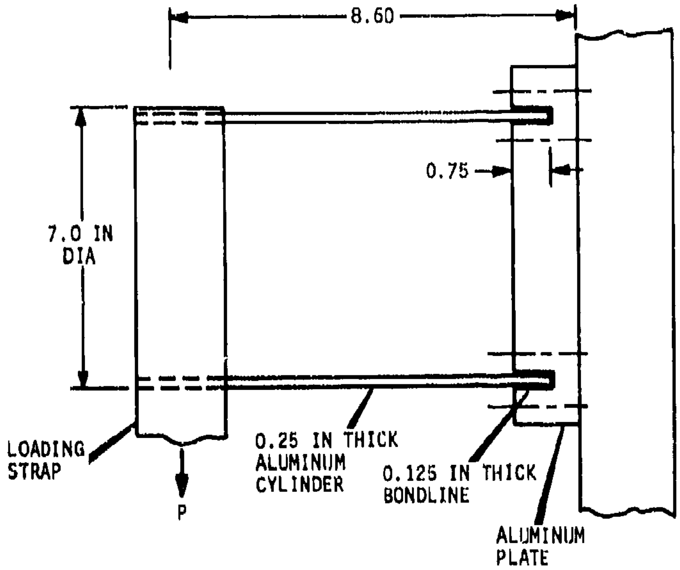


Figure 3-8. EA9309 Bond Strength Test Specimen

Table 3-IV EA9309 Bond Strength Test Results

Test	Failure Load, P (lbs)	Effective Avg. Bond Shear @ Failure (psi)	Required Strength @ Max. Test Loads (psi)	Factor of Safety
1	35000*	3980	3300	1.20
2	33000	4900	3300	1.48

* The load strap slipped off at 25,000 lbs. of load due to local deformation of the aluminum cylinder. It was then moved from its original location of 8.60 in. from the support to 6.60 in. from the support and the test was continued.

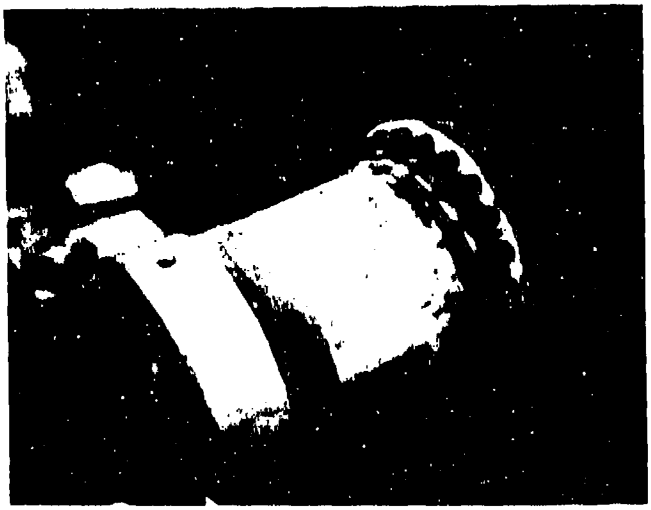


Figure 3-9. Test Specimen Showing Failure of Bonded Joint

4.0 TESTING OF SUBSCALE CONICAL SECTIONS

4.1 Test Objectives and Procedures

The primary objective of the subscale testing program is to determine the structural behavior of the shell sections under various loading conditions. A conical shell, due to its curvature, cone angle and fabrication techniques, behaves differently from a flat panel with the same laminate design. Subscale testing provides the design data required prior to full scale development. Instrumentation was provided to measure strains and deflection of the shells under test loads.

Analytical results were compared with the test data to check the analytical methods employed.

The primary design loads on the shell are axial compression and bending. The test loading conditions were established so that the failure loads would represent an envelope of the combined loads of axial compression and bending imposed on the conical shell.

All shells were subjected to static load tests. Loads were provided by hydraulic jacks positioned at appropriate locations with respect to the shell for the loading conditions. Load/deflection and load/strain plots were obtained for each test. Failure loads and modes were recorded.

4.1.1 Loading Conditions

A total of 10 static tests were conducted in the Martin Marietta Structures Test Laboratory on ten conical shells. The detailed test procedures are included in Appendix D. The loading condition for each of the 10 conical shells is described in the following paragraphs. The first group consists of specimens 001 through 005 and the second group consists of specimens 006 through 010. A number of tests in the second group are duplications of those conducted in the first group.

Test 1

Conical shell 004 was tested in axial compression. The shell was placed between two steel load plates, and the assembly was installed upright on top of the 200 Kips hydraulic jack with its shaft extending through the center of the assembly. A steel yoke was threaded onto the shaft to secure the assembly. The test setup is shown in Figure 4-1.

Loads were monitored by the use of a pressure gage which was calibrated prior to testing by means of a load cell. Twenty one axial type strain gages (FAE 25S-12S6) were installed to measure the surface strains and two DCDT's were placed between the top and bottom aluminum rings to measure the overall axial displacement of the shell under axial compression loading. The locations of the gages are shown in Appendix D.

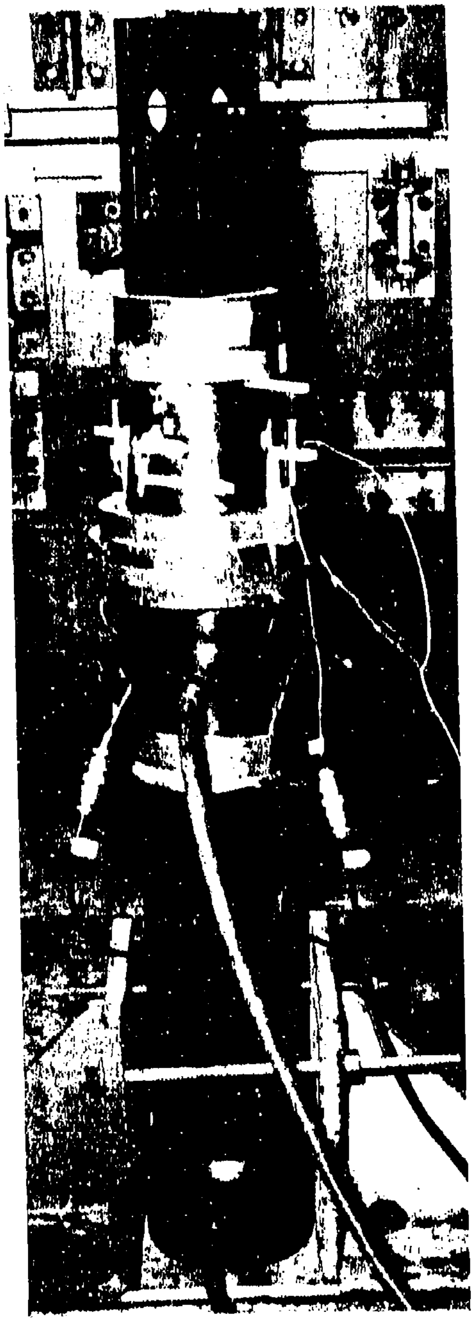


Figure 4-1. Test Setup - Axial Compression Test

Test 2

Conical shell 001 was tested in simple cantilever loading. The base aluminum rings were mounted to a steel column through a steel adapter plate having forty six (46) 5/16 inch bolt holes matching those in the base rings. The smaller end was bolted to a steel loading fixture which has lugs provided for the application of shear, bending and axial loads. For this test a single shear load was applied. A 20 Kips hydraulic jack was used to apply the load. The test setup is shown in Figure 4-2. This loading condition provided a point on the failure envelope along the abscissa where the axial compression is zero.

Eighteen strain gages were installed on the shell specimen. Four DCDT's were used to measure deflections. The locations of the instrumentation are shown in Appendix D.

Test 3

Conical shell 002 was tested under combined design loads. The base aluminum rings were mounted to a steel column through a steel adapter plate as in Test 2. The loading fixture was bolted to the other end of the specimen. Aluminum straps formed to fit the speciment contour were connected to a 20 Kip hydraulic jack to simulate external pressure loading. Another 20 Kip jack attached to the loading fixture applied the shear load. Two 100 Kip jacks were used to apply axial loads and couple loads (bending moment). This combined load condition corresponds to the design condition for the conical shell. The structure was designed to withstand ultimate loads equal to 150 percent of the combined design loads. The test setup is shown in Figure 4-3.

Eighteen strain gages and four DCDT's were installed for this test to measure the strains and deflections under the test loads. They are shown in Appendix D.

Test 4

Conical shell 003 was tested under a combined loading with axial compression held constant at 53,334 lbs. The test setup, loading apparatus and instrumentation were the same as those for Test 3. This loading condition was selected to generate a point on the combined loading envelope. The constant compression load was chosen to be one-third of the axial compression failure load from Test 1 which was 160,000 lbs.

Test 5

Conical shell 005 was tested under combined loading with the bending moment at the base held constant at 64,667 in-lbs. This bending moment was produced by applying a percentage of the design limit loads in shear, bending moment and distributed pressure. The test setup, loading apparatus and instrumentation were the same as

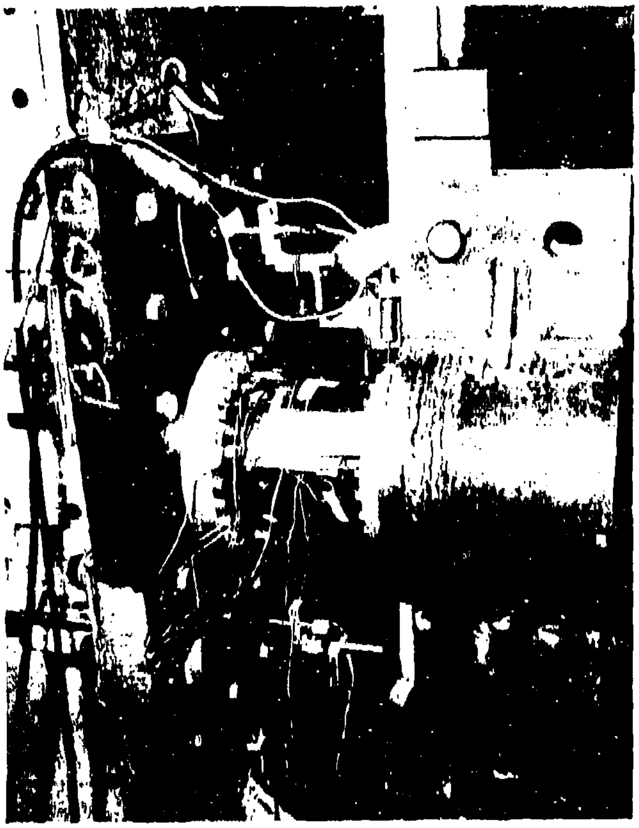


Figure 4-2. Test Setup - Shear/Bending Test

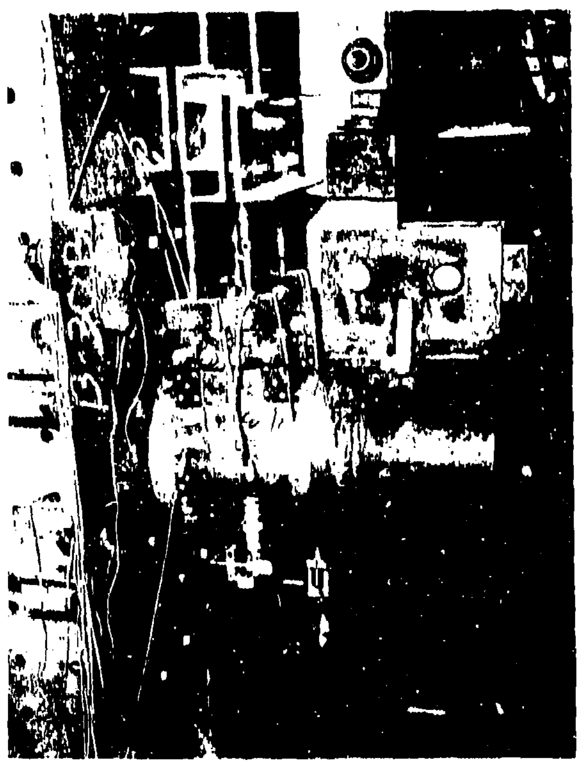


Figure 4-3. Test Setup - Combined Load Test

those for Test 3. This loading condition was selected to generate an additional point on the combined load failure envelope. The constant bending moment was chosen to be one-third of the failure bending moment from Test 2 which was 194,000 in-lbs.

Test 6

Conical shell 006 was tested in axial compression in the same manner as conical shell 004 in Test 1. Figure 4-1 shows the test setup. The strain gage data from Test 1 showed that some of the twenty one strain gage locations could be eliminated from Test 6 without penalizing the results. Therefore eleven strain gages were installed on conical shell 006 to measure surface strains. The locations of these gages are shown in Appendix D. Two DCDT's were also used to measure overall axial displacement of the shell.

Test 7

Conical shell 007 was tested under combined design loads in the same manner as conical shell 002 in Test 3. The test setup and loading apparatus were the same as those on Test 3 and are shown in Figure 4-3. Some of the strain gages were relocated to obtain more useful data. The DCDT's were also relocated to measure the true deflections of the shell. The locations are shown in Appendix D.

The loading condition is a repeat of Test 3. Since this is the design load condition, two tests were conducted to verify the structural integrity of the subscale conical shell. The combined load envelope includes both failure points.

Test 8

Conical shell 008 was tested under combined loading with axial compression held constant at 80,000 lbs. The test setup and loading apparatus are the same as those for Test 3. The locations of strain gages and DCDT's are the same as for Test 7. The axial compression load was held constant while the other loads were applied at increments until failure occurred. The magnitude of the compression load was selected to define the failure envelope in the high compression load region.

Test 9

Conical shell 009 was tested under combined loading with the bending moment at the base held constant at 64,667 in-lbs. This test had loading identical to Test 5. The location of strain gages and DCDT's are the same as Test 7.

Test 10

Conical shell 010 was tested under combined loading with axial compression held constant at 15,000 lbs. The test setup, loading

Table 4-I. Summary of Test Results

TEST	CONICAL SHELL NUMBER	LOADING CONDITION	FAILURE LOAD		TYPE OF FAILURE
			TEST	ANALYSIS	
1	004	COMPRESSION	160000 LB (AXIAL COMP)	166000 LB (AXIAL COMP)	OVERALL COMPRESSION FAILURE AT SMALL END
2	001	SHEAR/BENDING	20000 LB (SHEAR)	31300 LB (SHEAR)	LOCALIZED INTERLAMINAR SHEAR FAILURE AT LARGE END
3	002	COMBINED LOAD-SIMULTANEOUS	180% DESIGN LIMIT LOADS (DLL)	158% DLL	OVERALL COMPRESSION FAILURE AT LARGE END
4	003	COMBINED LOAD-CONSTANT COMPRESSION	53334 LB AXIAL COMP + 180% DLL FOR OTHER LOADS*	53334 LB AXIAL COMP + 139% DLL FOR OTHER LOADS*	OVERALL COMPRESSION FAILURE AT SMALL END
5	005	COMBINED LOAD-CONSTANT BENDING MOMENT AT LARGE END	64662 IN-LB BENDING MOMENT AT LARGE END + 540% AXIAL COMP DLL	64662 IN-LB BENDING MOMENT +700% AXIAL COMP DLL	OVERALL COMPRESSION FAILURE AT SMALL END
6	006	COMPRESSION	180000 LB (AXIAL COMP)	166000 LB (AXIAL COMP)	OVERALL COMPRESSION FAILURE AT SMALL END
7	007	COMBINED LOAD-SIMULTANEOUS	200% DLL	156% DLL	COMPRESSION FAILURE AT LARGE END
8	008	COMBINED LOAD-CONSTANT COMPRESSION	80,000 LB AXIAL COMP + 150% DLL FOR OTHER LOADS*	80,000 LB AXIAL COMP + 104% DLL FOR OTHER LOADS*	COMPRESSION FAILURE AT SMALL END
9	009	COMBINED LOAD-CONSTANT BENDING MOMENT AT LARGE END	64662 IN-LB BENDING MOMENT AT LARGE END + 720% AXIAL COMP DLL	64662 IN-LB BENDING MOMENT + 700% AXIAL COMP DLL	COMPRESSION FAILURE AT SMALL END
10	010	COMBINED LOAD-CONSTANT COMPRESSION	16000 LB AXIAL COMP + 170% DLL FOR OTHER LOADS*	16000 LB AXIAL COMP + 175% DLL FOR OTHER LOADS*	LOCALIZED INTERLAMINAR SHEAR AND BOND FAILURE AT LARGE END

*OTHER LOADS ARE BENDING MOMENT, SHEAR AND LATERAL PRESSURE LOADS.

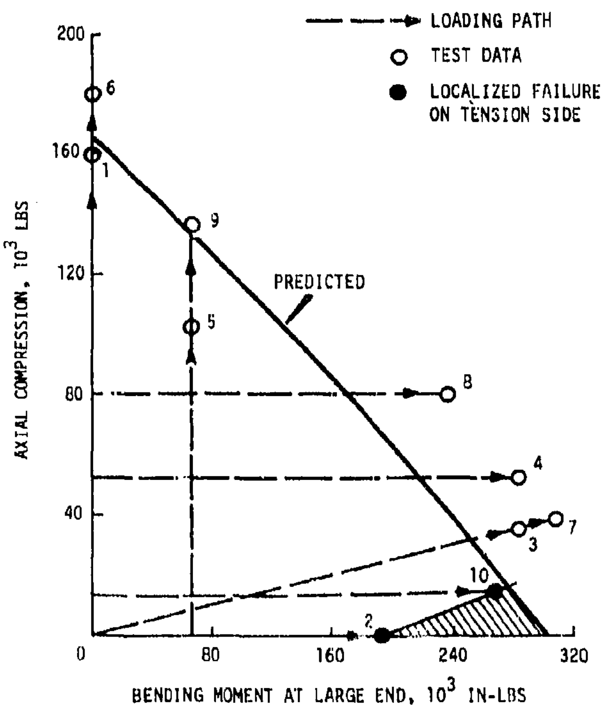


Figure 4-4. Load Interaction Diagram

apparatus and instrumentations are identical to those of Test 8. The compression load of 15,000 lbs. was selected to define the combined load failure envelope in the low compression load region.

4.2 Test Results

The failure loads and modes resulting from the static load tests conducted on the ten subscale conical shells are summarized in Table 4-I. The failure loads from these tests are also shown graphically in relation to the analytically predicted failure load envelope in Figure 4-4. The combined load diagram shows the scatter of the test points. Tests 1 and 6 have a spread of 10,000 lbs. from the mean value, or approximately ±6 percent variation. The strain readings indicate maximum strains for Tests 1 and 6 of 0.0022 in/in and 0.0028 in/in respectively. The measured difference of surface strains could be caused by variations of basic material properties or variables in the hand layup method. A variation of 17,000 lbs. or about ±14 percent exists for Tests 5 and 9 from the mean value. The failure loads of Tests 3 and 7 have a variation of ±10 percent from the mean test value. Scatter of approximately ±10 percent is considered to be normal for laminated graphite/epoxy composite material.

All tests except for the two axial compression tests have exhibited localized failures as indicated by discontinuities in strain gage data. These initial localized failures were followed by stress redistributions which allowed the shell to continue to carry increased load until ultimate failure occurred. Strain gage data from Test 5, for example, revealed that local failure had occurred at 360 percent of Design Limit Load (DLL) or 69,000 lbs. Stress redistribution within the shell after the initial failure allowed the shell to continue to carry load up to 540 percent of DLL or 103,000 lbs.

The predicted failure load envelope for the combined loads is based on laminate analysis which computes the stresses and strains of each ply of the laminate assuming every ply is effective in resisting loads at any section of the shell. The assumption is substantiated by the test results except for a small region where the local tension loads due to bending moment cause the interlaminar shear strength of the epoxy resin to be exceeded. This small region is bounded by test points 2 and 10 and is shown as cross-hatched area in Figure 4-4.

Most of the test failure points fell somewhat above the predicted failure envelope. This was the result of the analysis being based on a failure stress of 90 ksi and a failure strain of 0.0021 in/in while the actual strength properties of the specimens made from GY70/Fiberite 934 prepreg tape were higher. After adjusting for actual specimen material properties, good correlation between test and analytical values was obtained. Discussion of the test data and correlation with analytical results are given in the next section.

4.3 Test Data Analysis and Correlation for Basic Shells

This section is devoted to detailed discussions of the test data and the correlation of test data with analytical results. All test data are included in this section in the forms of plots of load/deflection, load/strain and stress/strain. Data of similar tests are grouped together for convenience in discussion and data correlation. The tests can be classified as follows:

Axial Compression - Tests 1 and 6 (Conical shells 004 and 006)

Combined Design Loads - Tests 3 and 7 (Conical shells 002 and 007)

Combined Loads With Constant Bending Moment - Tests 5 and 9 (Conical shells 005 and 009)

Combined Loads With Constant Axial Compression - Tests 4, 8 and 10 (Conical shells 003, 008 and 010)

Shear/Bending - Test 2 (Conical shell 001)

Conical shells 001 through 005 had failure loads consistently lower than those of conical shells 006 through 010 for the comparable tests. General Dynamics, the shell fabricator, indicated that the first five were made from prepreg lot 4-E-20 and the second five from prepreg lot 4-E-31. The latter showed higher flexure strength but lower fiber tensile strength at room temperature on the material certification based on the supplier's test data. The higher flexure strength was expected to give higher failure loads and higher modulus.

The discussion of the test data and correlation with analytical results for each of the above tests are given in the following paragraphs.

4.3.1 Axial Compression (Tests 1 and 6)

The compression load was applied uniformly to the shell cross section by the use of 3-inch thick steel loading plates. The compressive stress at any cross-section can be computed simply by dividing the test load by the cross sectional area. The stresses were thus computed at the three sections where strain gages were located. The stress/strain plots for Test 1 are shown in Figures 4-5 through 4-7. It is evident from the plots that the stress/strain relationship in compression is not linear. The initial modulus, E_i, has an average value of 24.1×10^6 psi and a tangent modulus, E_t, near the point of failure has an average value of 16.5×10^6 psi.

The stress/strain plots for Test 6 are shown in Figure 4-8 through 4-10. The average value of the initial modulus is 25.8×10^6 psi and the average tangent modulus near the failure point is 16.2×10^6 psi.

By using the secant modulus of 22.5×10^6 psi obtained from the stress/strain plots of the test data and an ultimate strain of 0.0021 in/in, the failure load was calculated to be 166,000 lbs. The SLADE finite element model (Figure 3-2) and KLIGER code were used in the computation of the failure load.

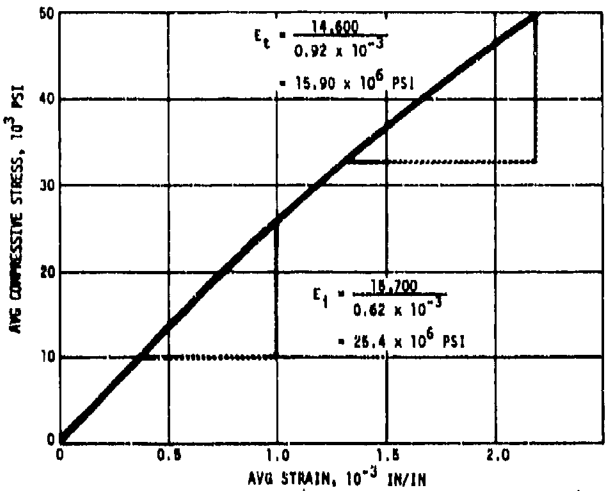


Figure 4-5. Stress/Strain Plot at Small End - Test 1 - Axial Compression

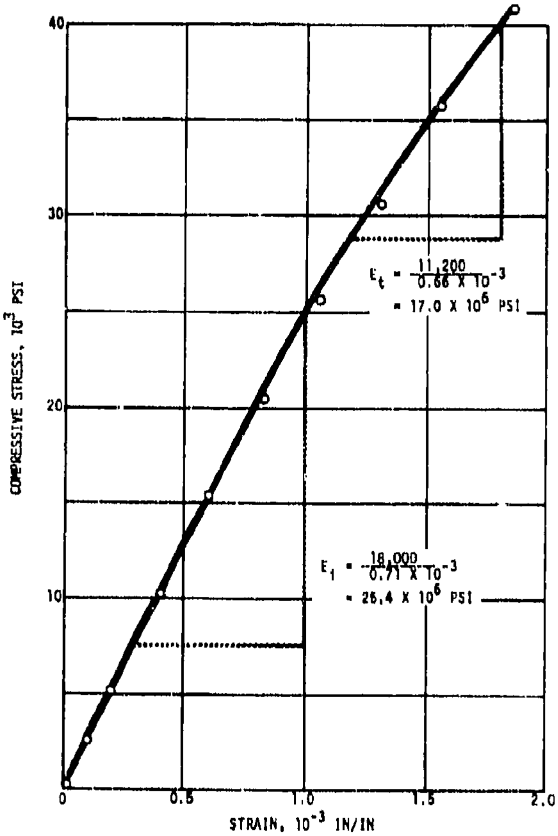


Figure 4-6. Stress/Strain Plot at Mid Section - Test 1 - Axial Compression

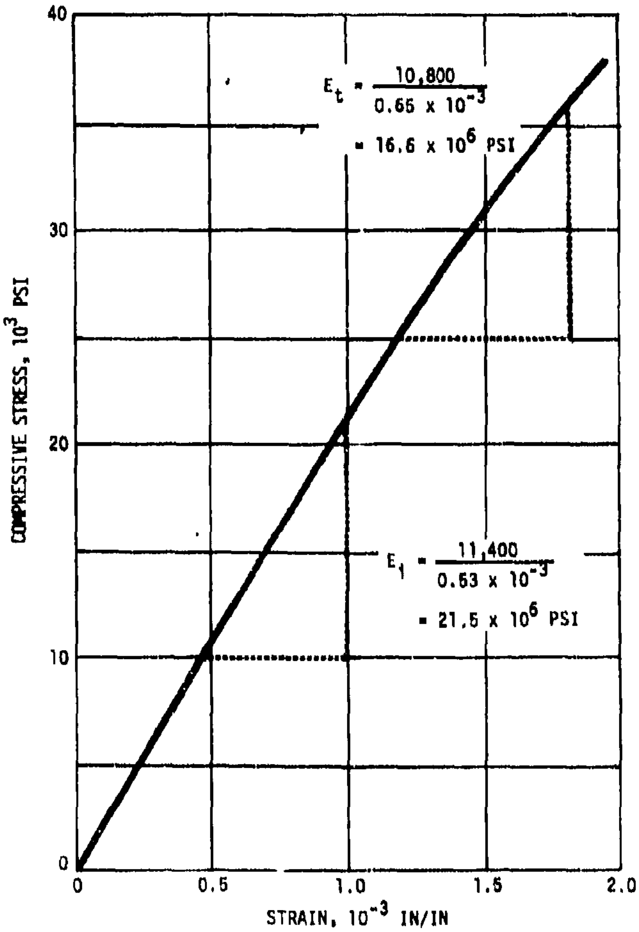


Figure 4-7. Stress/Strain Plot at Large End - Test 1 - Axial Compression

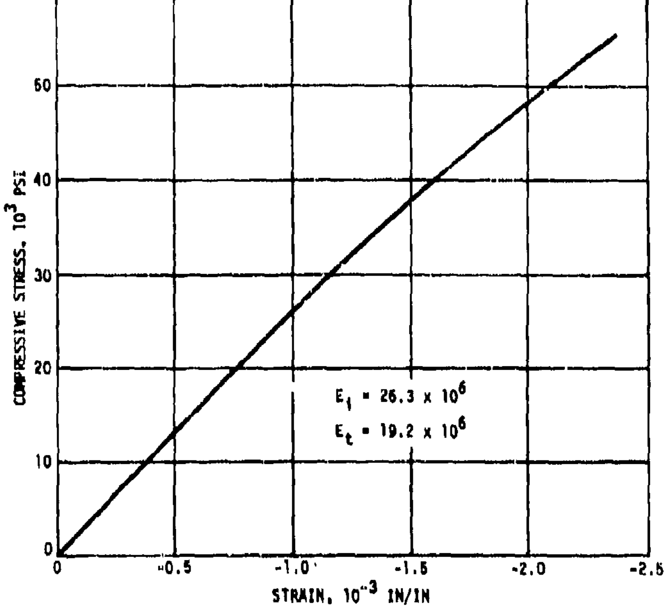


Figure 4-8. Stress/Strain Plot at Small End - Test 6 - Axial Compression

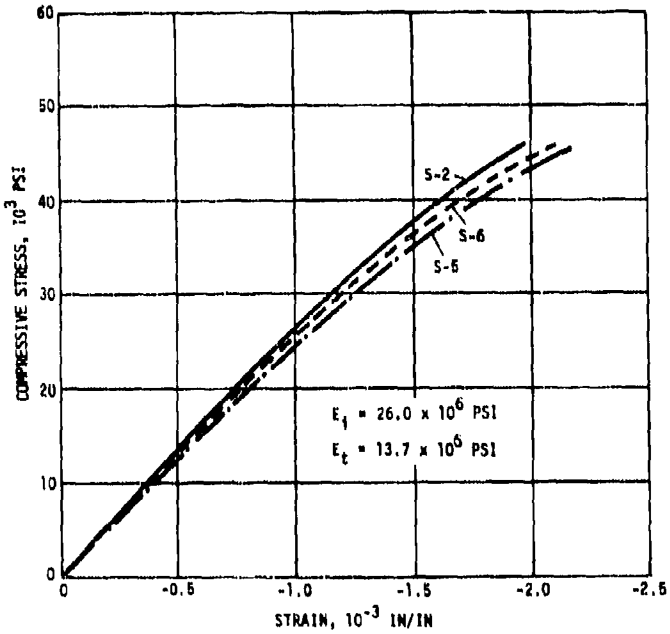


Figure 4-9. Stress/Strain Plot at Mid Section - Test 6 - Axial Compression

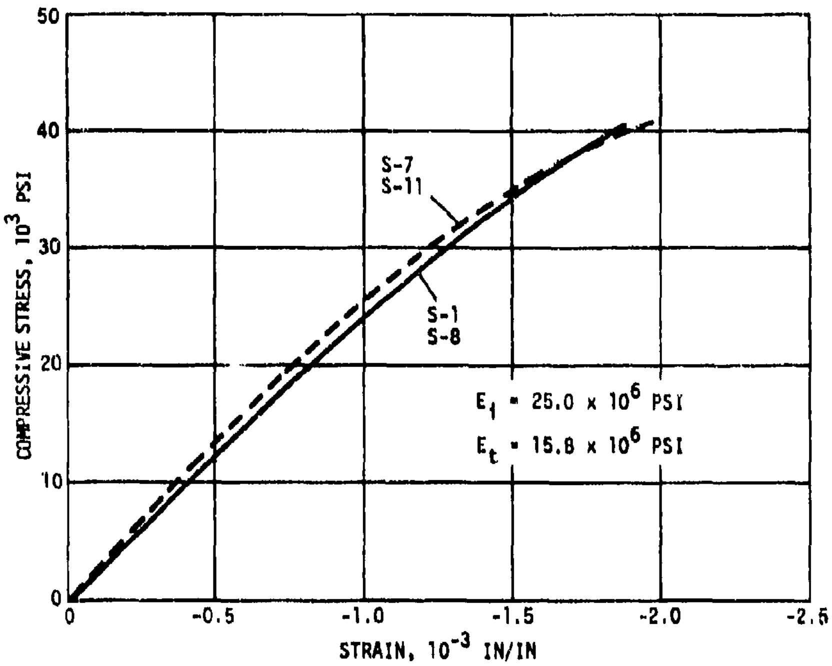


Figure 4-10. Stress/Strain Plot at Large End - Test 6

The load/deflection plots for the two tests are shown in Figures 4-11 and 4-12. The non-linearity of the stress/strain relationship is reflected in the deflection plots. The deflections predicted by analysis are also plotted along with the test points for comparison. These analytical deflections are based on the average secant modulus obtained from stress/strain data on Tests 1 and 6; therefore, a direct comparison can be made between the test and analytical results. It is judged that the correlation is quite good and the gore patterns of the layers apparently have no adverse effects on the strength and stiffness of the conical shell structure.

4.3.2 Combined Design Loads (Tests 3 and 7)

Strain gage data are shown in plots of percent Design Limit Load (DLL) versus strain in Figures 4-13 through 4-18. The load/strain data are more useful and informative than stress/strain data in the evaluation of the laminated conical shell under combined loads. The shell stresses computed from the applied loads are valid only in the low stress regions where the stress strain plot is linear. In the non-linear regions of the stress/strain

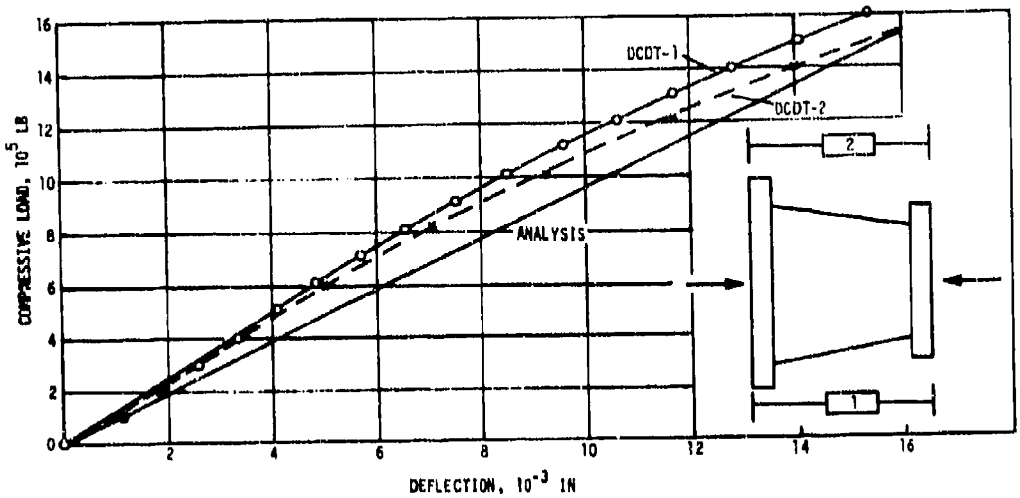


Figure 4-11. Shell Axial Deflection - Test 1

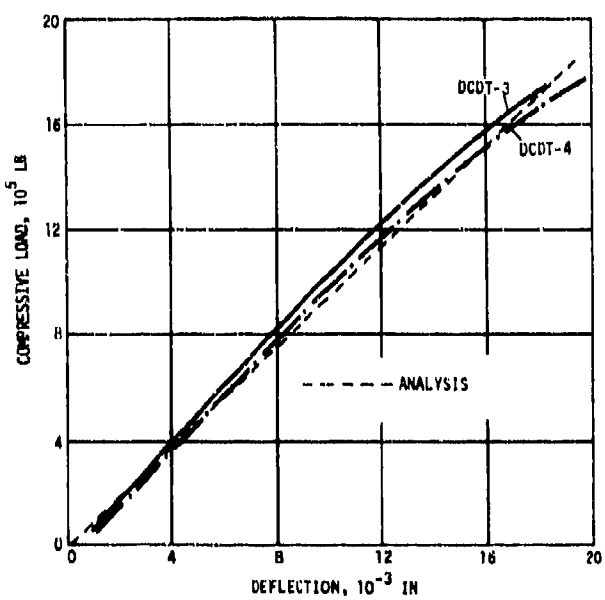
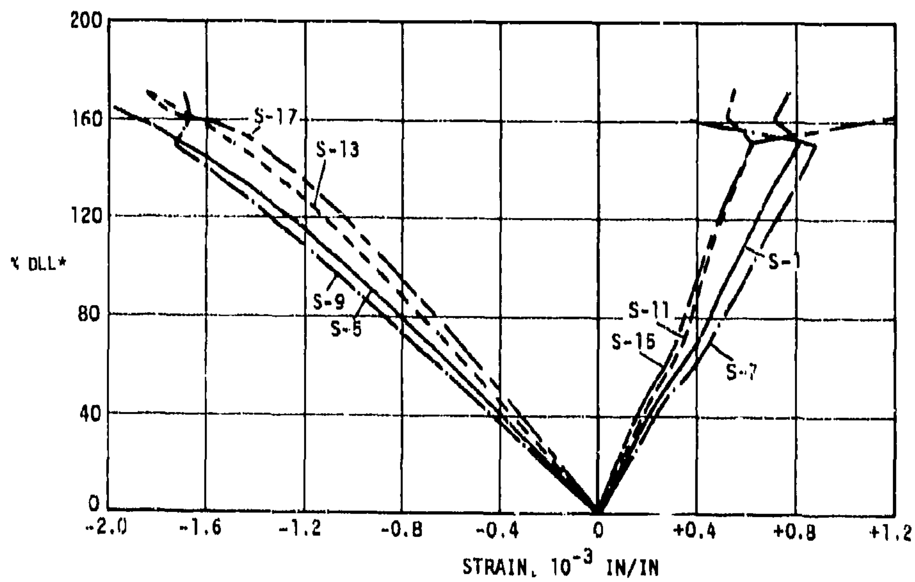


Figure 4-12. Shell Axial Deflection - Test 6

curve, where tensile modulus is not necessarily equal to compressive modulus, the effective neutral axis will shift away from the centroidal axis of the section and accurate stress computation becomes very complex. Therefore, load/strain data are used to evaluate the structural behavior of the laminated conical shell under bending loads.

Examination of the strain gage data of Test 3 (Figures 4-13 through 4-15) showed that an initial local failure occurred at 150 percent to 160 percent Design Limit Load on the tension side of the outer layers near the fixed end as evidenced by a sudden drop of strain in gage S-7. It is seen that the tension load was transferred to the inner layers as shown by the abrupt increase in strain in gage S-15. The redistribution of tension load also caused the discontinuities in gage S-1 and S-11 and their corresponding transverse gages (S-2 and S-12) through the Poisson's ratio effect.

The redistribution of loads had the effect of increasing compressive strains as evidenced by gages S-5, S-13, S-9 and S-17. The load/strain slopes are significantly decreased because of the higher compressive strains resulting from local tension failure. At 170 percent DLL, the shell collapsed.



*DLL - Design Limit Load

Figure 4-13. Percentage Load/Strain - Axial Gages, Test 3 - Combined Design Loads

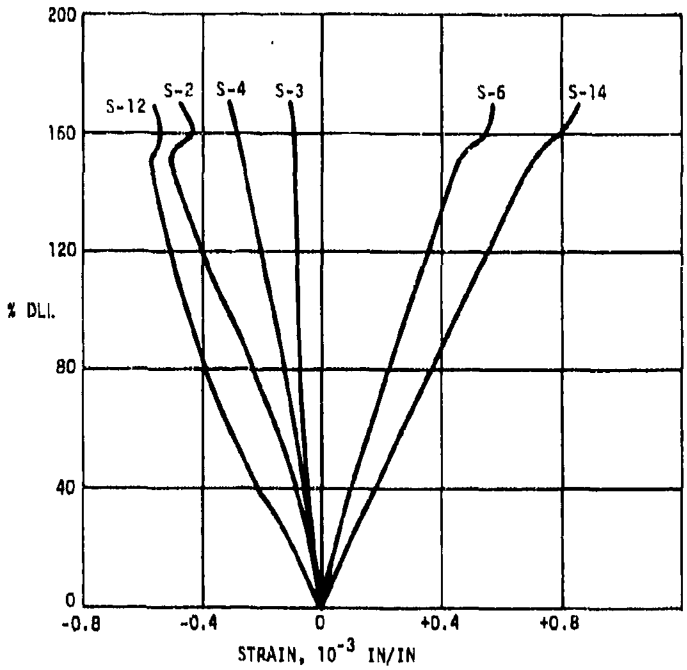


Figure 4-14. Percentage Load/Strain - Test 3 - Combined Design Loads

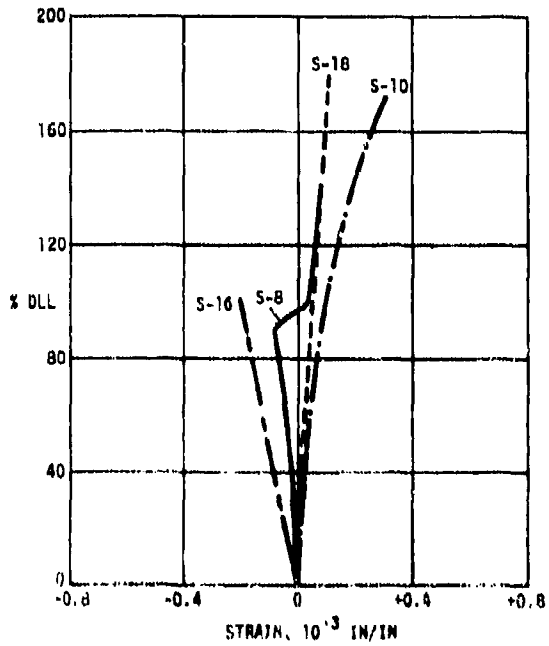


Figure 4-15. Percentage Load/Strain - Test 3 - Combined Design Loads

Strain gage data from Test 7 exhibited a similar structural response of the laminated shell to the combined loads, except that the local tension failure occurred at 130 percent DLL and the shell specimen failed at 200 percent DLL. The initial failure started at lower load yet overall failure occurred at higher load than in Test 3. Careful examination of the gages on the tension side of the two specimens led to the conclusion that specimen 007 had a more uniform load redistribution than specimen 003 following initial failure. See Figures 4-16 through 4-18.

A failure load of 158 percent DLL was predicted by analysis based on unidirectional failure stress of 90,000 psi, unidirectional failure strain of 0.0021 in/in and a composite modulus of 26.7 x 10^6 psi. The specimen material had higher unidirectional failure stress and strain but lower composite modulus. The analysis employed a linear stress/strain relationship; however bending modulus effect, if any, was not accounted for. Therefore the net effect was that the analysis tended to yield conservative results. For design purposes, this conservative approach is acceptable.

The secant modulus used in the axial compression failure load computation is not directly applicable for the analysis of the combined loadings because under combined loads the shell is subjected to tensile and compressive stresses where the effective tensile modulus does not correspond to the compressive secant modulus. Therefore, a theoretical composite modulus of 26.7 x 10^6 psi was used in the laminate analysis.

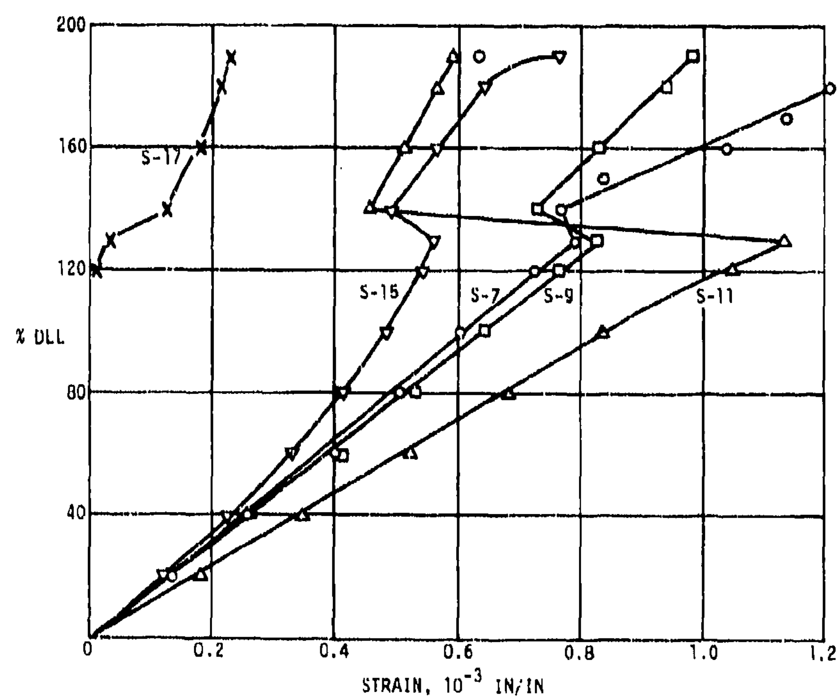


Figure 4-16. Load/Strain Plots - Test 7 - Combined Design Loads

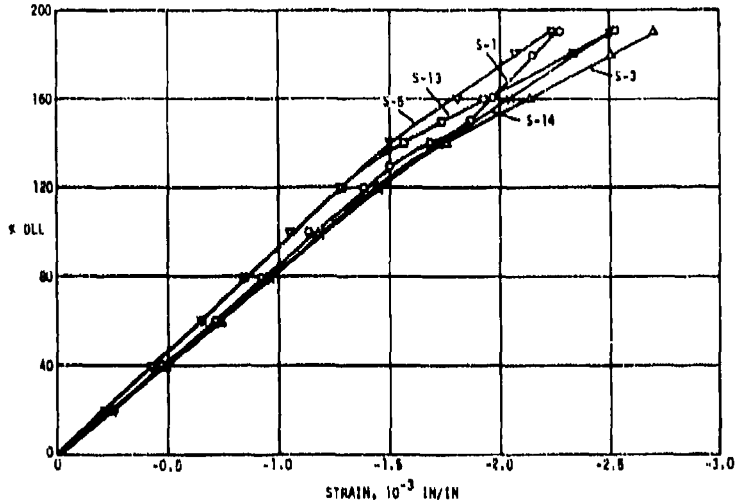


Figure 4-17. Load/Strain Plots - Test 7 - Combined Design Loads

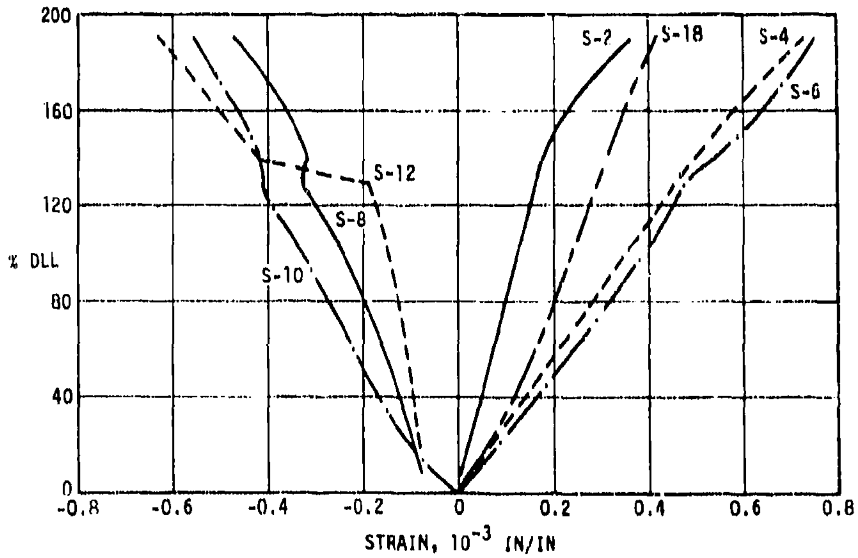


Figure 4-18. Load/Strain Plots - Test 7 - Combined Design Loads

The cantilever deflections of the small end are shown in Figures 4-19 and 4-20. The deflection from Test 3 represents the overall end deflection including the effects of the support structure. Test 7 had DCDT's located so that the true deflection of the cantilevered graphite shell could be calculated without including the deformation of the support structure. The analytical results should approach the deflections of Test 7. However, as can be seen from Figures 4-20, the analytical results give nearly twice the deflection as the test results at 100 percent DLL. A possible explanation is that the hydraulic jacks had a restraining effect on the shell deflections.

It is significant to note that GY70/epoxy composite, known as an ultra high modulus, brittle material, can withstand local tensile failures without rapid propagation to rupture. When a local tensile failure occurred, a stress redistribution took place around the fracture and the composite structure was able to continue to resist loads.

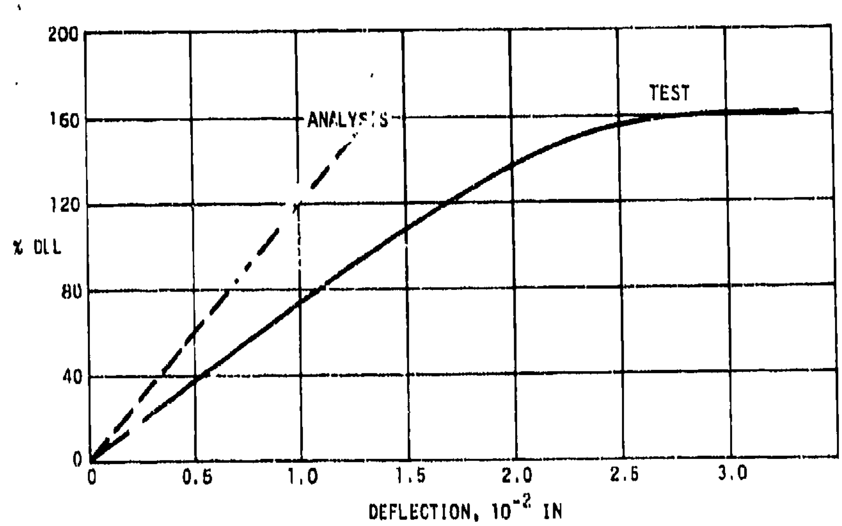


Figure 4-19. Shell Cantilever Deflection - Test 3 - Combined Design Loads

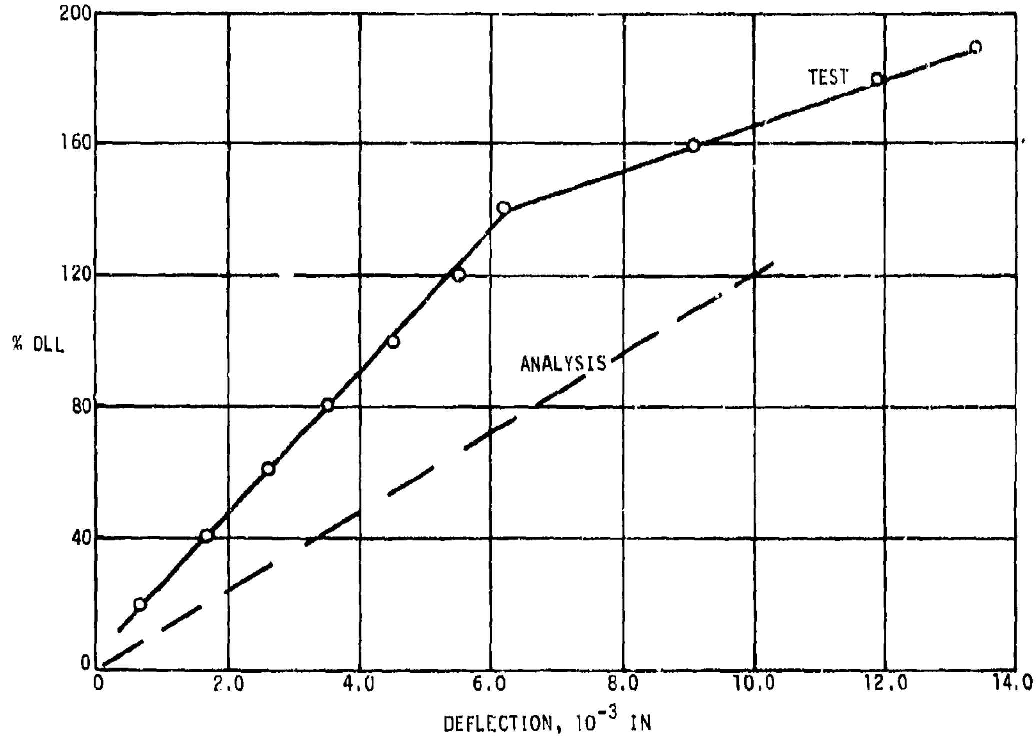


Figure 4-20. Shell Cantilever Deflection - Test 7 - Combined Design Loads

4.3.3 Combined Loads With Constant Bending Moment (Tests 5 and 9)

A bending moment of 64,667 in-lb. at the supported end was applied as an initial loading. The bending moment was generated by shear, bending moment and lateral pressure loads in the same proportion as in the combined design load condition (Tests 3 and 7). It was arbitrarily chosen as one-third of the bending moment capability at the supported end as determined by test.

The strains indicated by the gage readings are comprised of the strains from direct loading and those from Poisson's ratio effects. The equations for the resultant strains are as follows:

$$e_L = \frac{\sigma_L}{E_L} (1-\nu_{TL}\ \nu_{LT}) - \nu_{TL}\ E_T$$

$$e_T = \frac{\sigma_T}{E_T} (1-\nu_{LT}\ \nu_{TL}) - \nu_{LT}\ e_L$$

where subscripts L = longitudinal (along shell axis)

T = transverse (circumferential)

Test 5 and 9 were subjected to the same loading condition. Test 5 resulted in a failure load of 540 percent of Design Limit Compression Load (DLCL) which is lower than the predicted failure load of 700 percent. Examination of the strain data, shown in Figure 4-21, revealed that an initial compressive failure occurred at 360 percent DLCL as evidenced by strain discontinuities on gages S-1, S-7, S-11 and S-15. A change of load path allowed the specimen to resist increased loads. The fact that initial failure occurred at a relatively low compressive strain (-0.32×10^{-3} in/in) led to the conclusion that some defects existed in the specimen. Visual examination of the failed specimen suggested that the failures started near the small end.

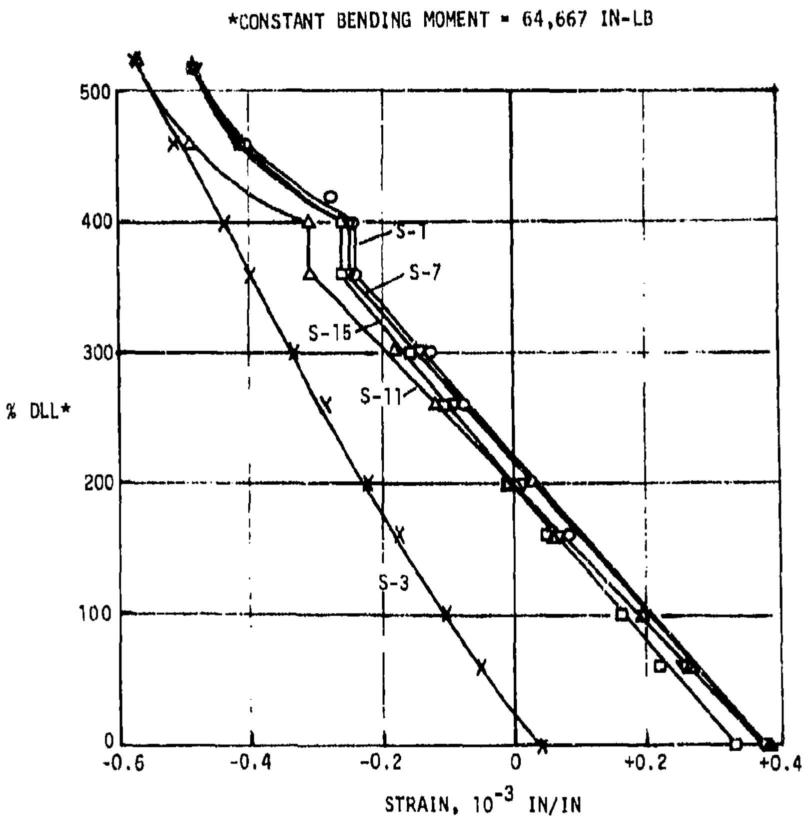


Figure 4-21. Load/Strain Plots - Test 5 - Combined Loads with Constant Bending Moment

In Test 9, the specimen failed at 720 percent DLCL. Strain gage readings appear to be normal. They are linear at low strains and become slightly non-linear in the high strain region.

It should be noted that the 100 percent Design Limit Compression Load is 19,100 lbs. The seemingly high percentage of the compression load attained was due to the relatively low bending moment applied for this condition.

Since the loading is predominantly axial compression, the DCDT measurements intended to obtain lateral shell deflections are not significant.

4.3.4 Combined Loads With Constant Axial Compression (Tests 4, 8, and 10)

A constant axial compression load of 53,334 lbs. was applied to the specimen in Test 4 prior to the application of shear and bending moment in increments. The value was arbitrarily chosen to be one-third of the compressive failure load of 160,000 lbs. so that a failure point could be generated in that region of the combined load envelope. Strain gage data appear to be normal except in S-9 and S-7 which show strain discontinuities indicating localized failure or cracks (see Figures 4-22 and 4-23). The probable cause could be either microcracking or high locked-in stresses developed in the curing of the shell. GY70 composite has a coefficient of thermal expansion of -0.58×10^{-6} in/in/°F in the fiber direction and 17.6×10^{-6} in/in/°F transverse to the fiber. Therefore, due to the large mismatch in thermal strains, microcracks are very likely to occur.

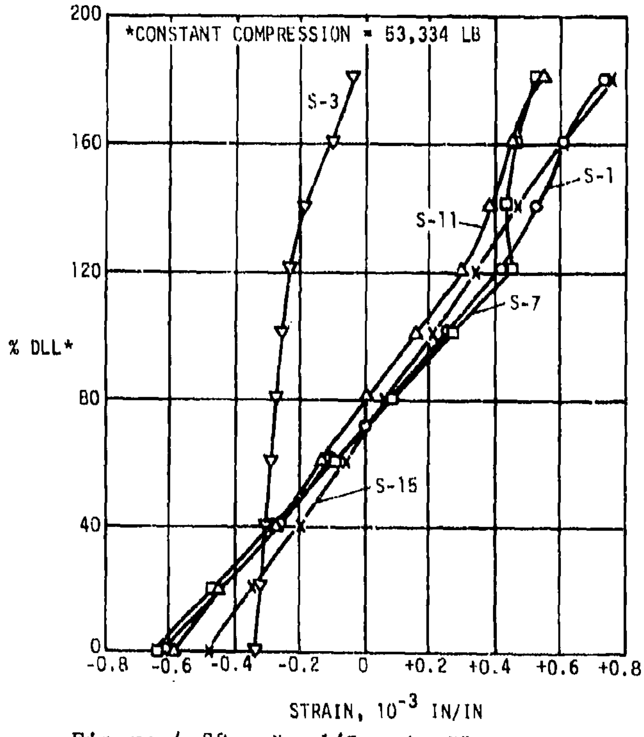


Figure 4-22. Load/Strain Plots - Test 4 - Combined Loads with Constant Compression

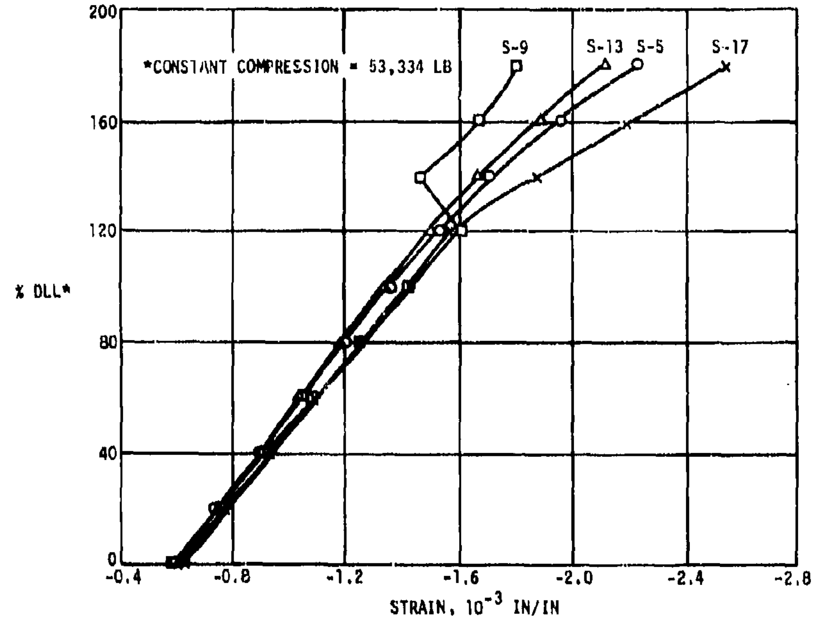


Figure 4-23. Load/Strain Plots - Test 4 - Combined Loads with Constant Compression

Test 8 had 80,000 lbs. constant compression load applied to the specimen before the increments of shear and bending loads were imposed. The significant strain data were those along the length of the specimens as shown in Figures 4-24 and 4-25. Gage S-1 exhibited a discontinuity at 130 percent of the Design Limit Shear and Moment (DLSM). The specimen fractured at 150 percent DLSM.

The load/deflection plots of the two tests are shown in Figures 4-26 and 4-27. For Test 4, the deflection includes the deformation of the test support structure and is shown for comparison purposes only. Analysis was not performed for the support structure deformation. The deflection for Test 8 was measured with respect to the support structure and therefore is the true cantilevered shell deflection. The results of the deflection analysis based on the SLADE computer code are shown by the dashed line. Twenty-two percent higher deflection is predicted by the analysis for the given loading; therefore, the analysis is conservative.

4.3.5 Shear/Bending (Test 2)

For Test 2, the initial failure occurred at 12,000 lbs. or 116,400 in-lbs. bending moment at the large end when a cracking noise was heard during the loading cycle. The strain gage data is shown in Figures 4-28, 4-29, and 4-30. Examination of the data and the failed specimen revealed that failure occurred in the outer layers of the tension side of the specimen at the supported end. The tension load transferred from the outer aluminum ring caused high local tensile stresses in graphite layers adjacent to the ring.

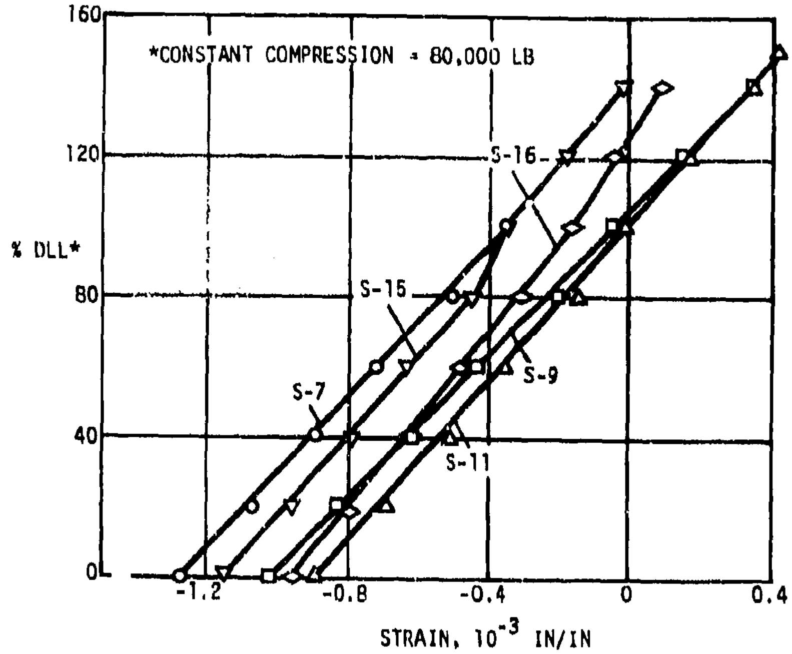


Figure 4-24. Load/Strain Plots - Test 8 - Combined Loads with Constant Compression

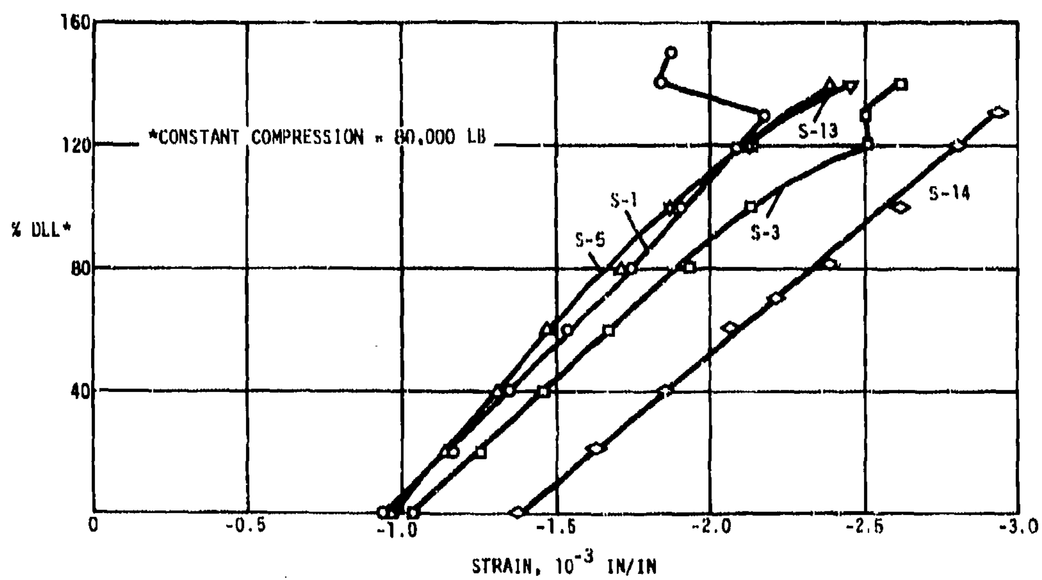


Figure 4-25. Load/Strain Plots - Test 8 - Combined Loads with Constant Compression

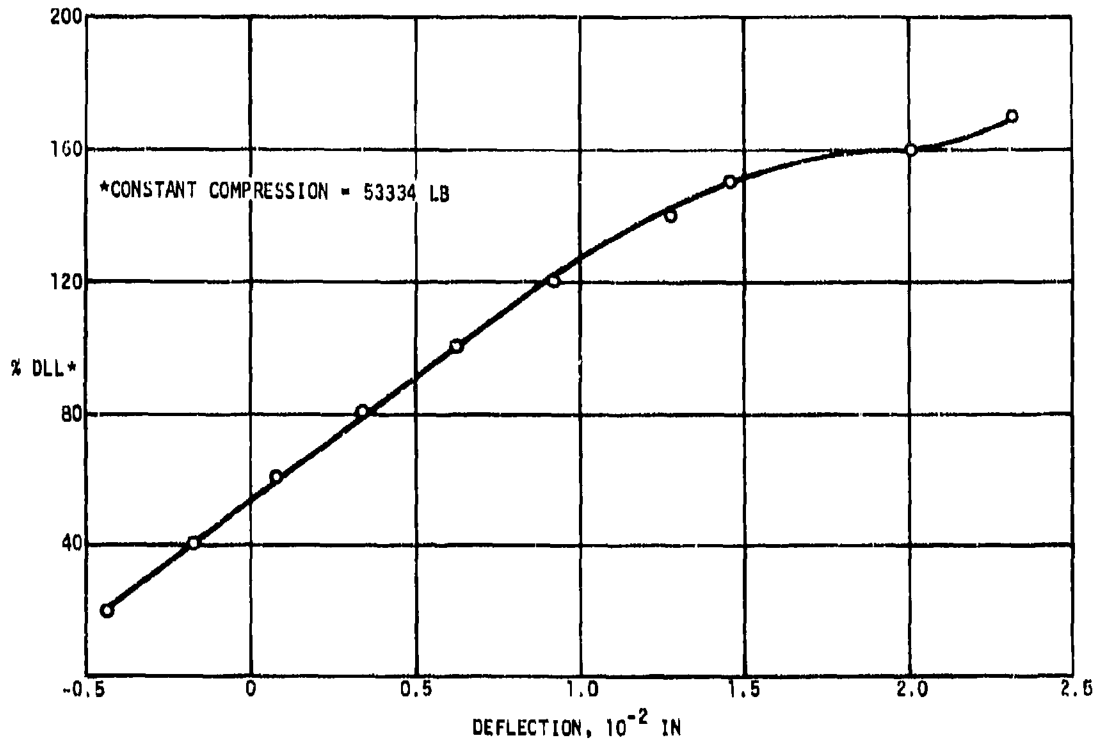


Figure 4-26. Shell Cantilever Deflection - Test 4 - Combined Loads with Constant Compression

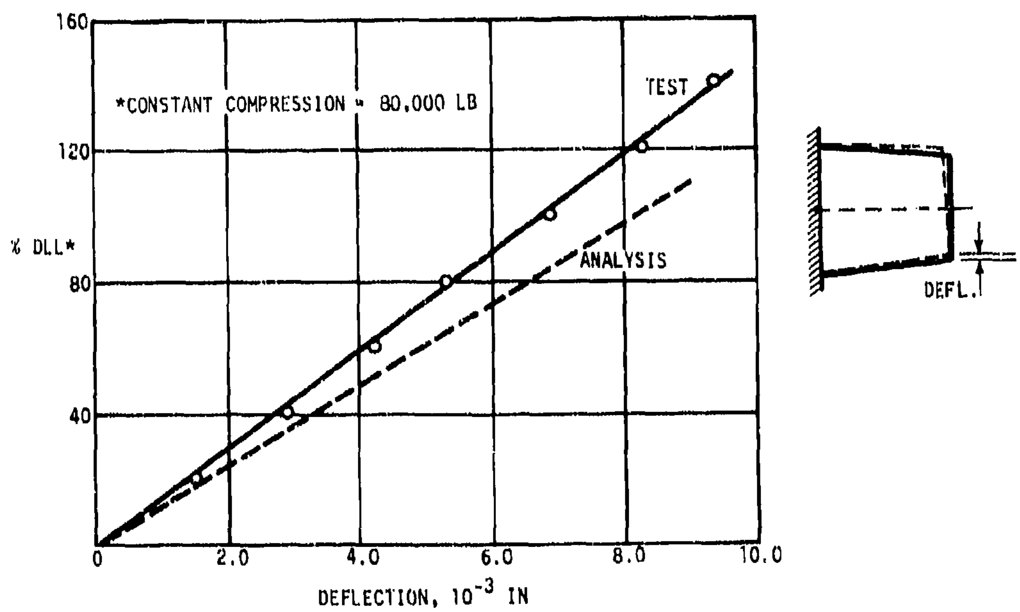


Figure 4-27. Load Deflection - Test 8 - Combined Loads with Constant Compression

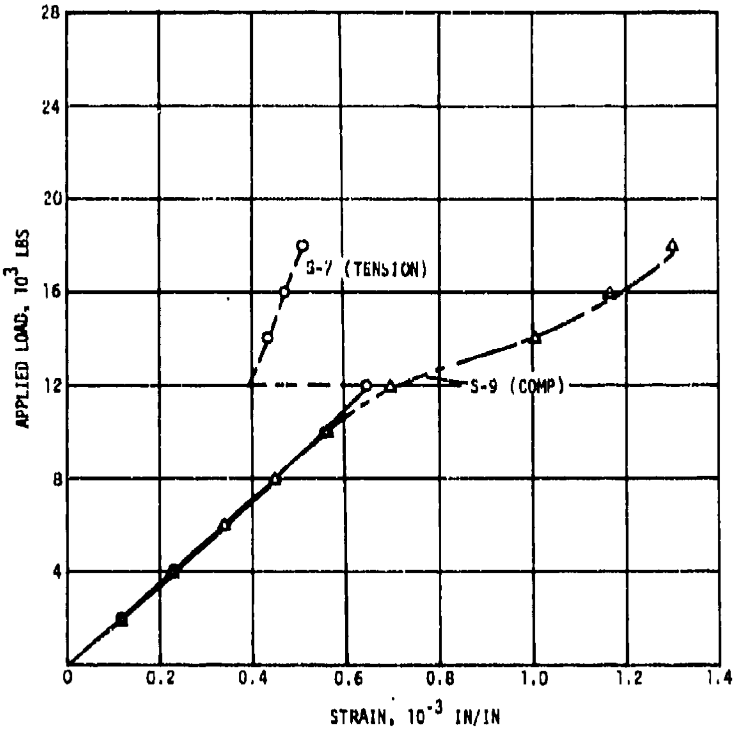


Figure 4-28. Load/Strain Plot - Test 2 - Shear/Bending

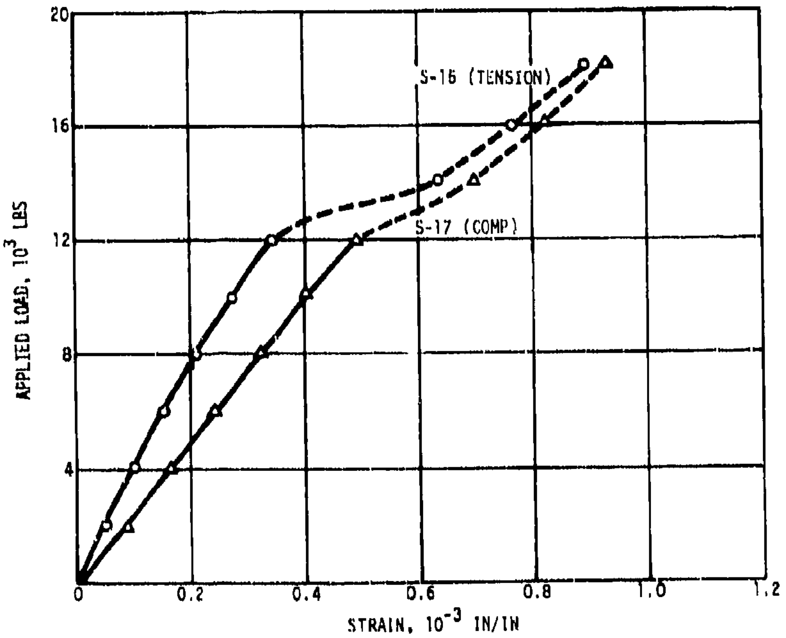


Figure 4-29. Load/Strain Plot - Test 2 - Shear/Bending

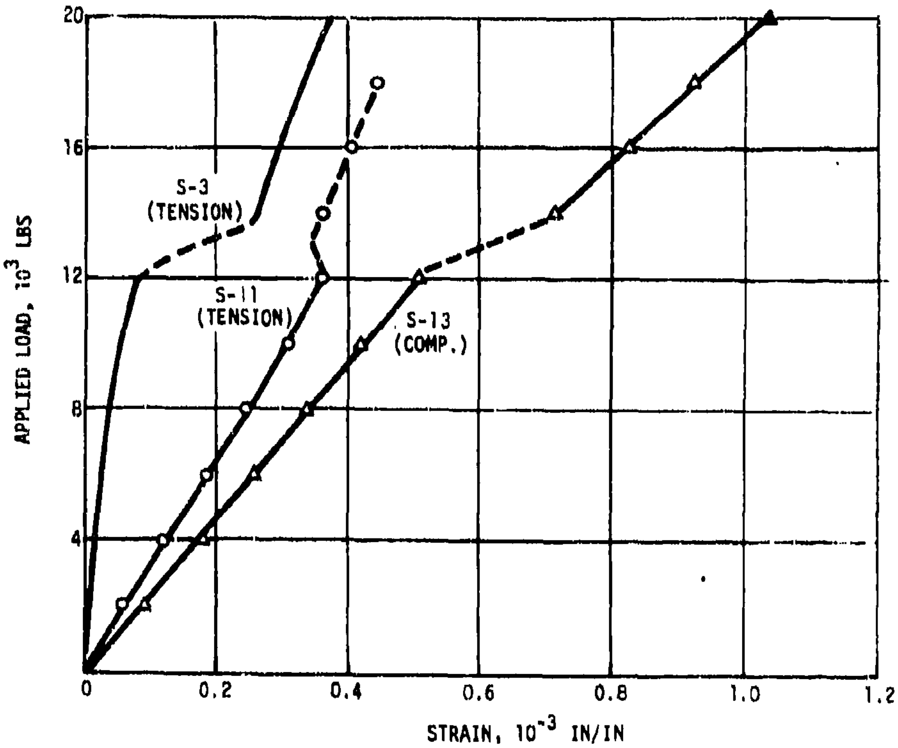


Figure 4-30. Load/Strain Plot - Test 2 - Shear/Bending

This high stress region was predicted by a TEXGAP finite element computer analysis. However, the finite element model did not have elements small enough in that region to accurately predict the stress level.

A small constant axial compression load, 15,000 lbs., was applied prior to the application of shear and bending load for Test 10. The compressive load did not prevent the localized tensile failure as experienced in Test 2. However, the failure occurred at a higher bending moment than that in Test 2 and provides another failure point to define the localized failure envelope as shown in Figure 4-4. The shaded region corresponds to localized tensile failure loads. Initial failure occurred at 60-80 percent DLL, and the shell continued to carry load to 170 percent DLL. Strain gage data are shown in Figures 4-31 and 4-32.

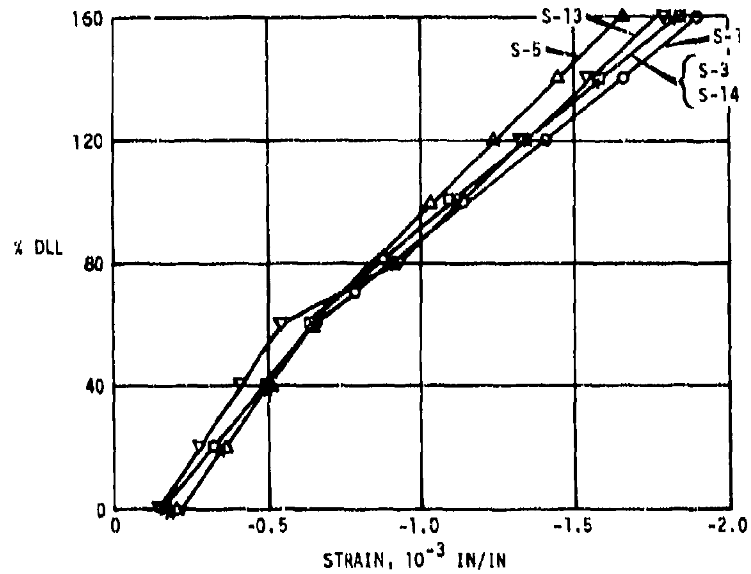


Figure 4-31. Load/Strain Plots - Test 10 - Combined Loads with Constant Compression

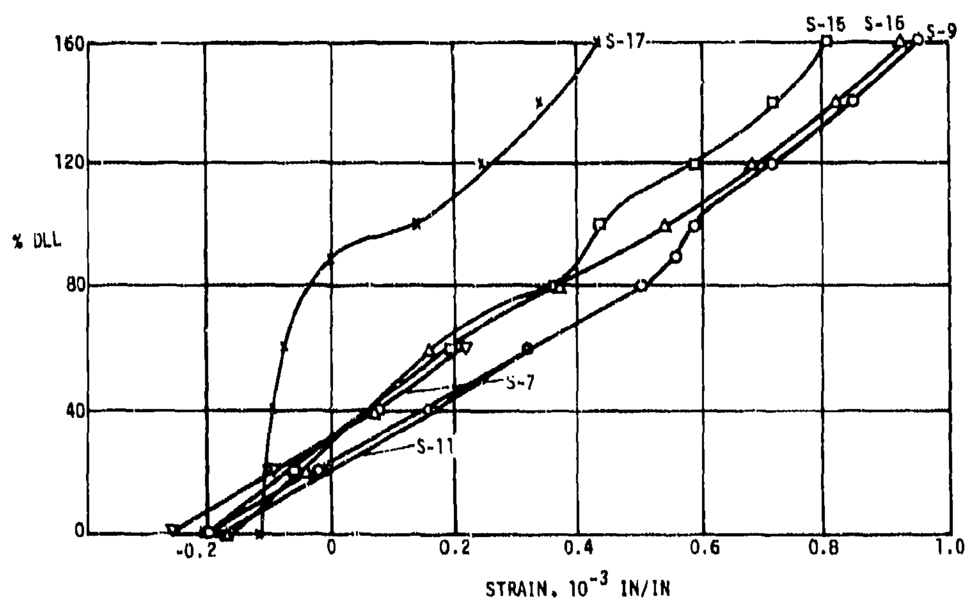


Figure 4-32. Load/Strain Plots - Test 10 - Combined Loads with Constant Compression

5.0 SHELL REINFORCEMENT EVALUATION

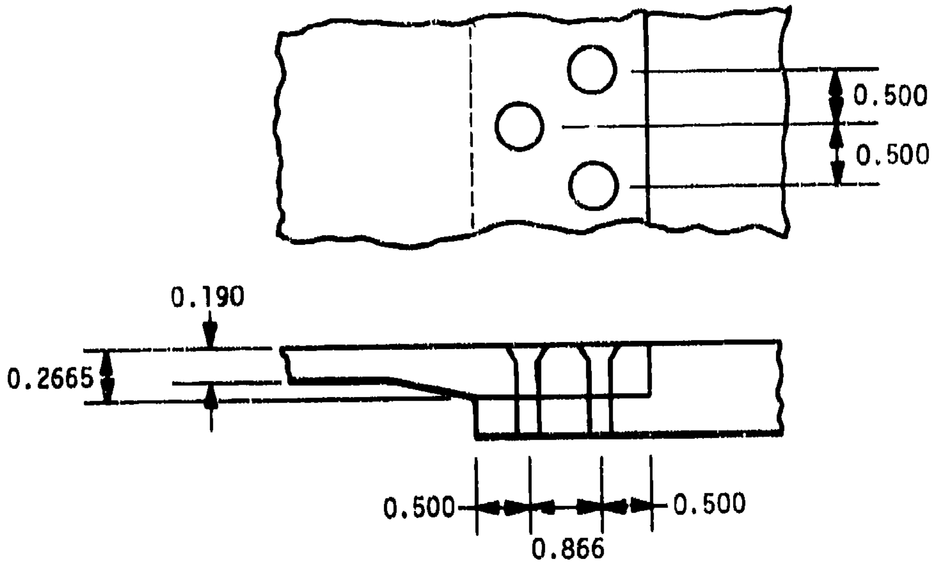
Splice joints for top stage sections of advanced interceptors are required to carry high loads and to possess high stiffness. GY70/Epoxy shell structures for the missile sections have to be reinforced at the bolted splice joints to meet the strength and stiffness requirements.

A design and analysis of splice joint reinforcements was conducted. First a literature survey was made to evaluate the state-of-the-art joint reinforcements for graphite/epoxy aerospace structures. Visits were made to the Denver Division and Baltimore Division of Martin Marietta Corporation. Denver Division has used GY70 in space structure applications. Baltimore Division has fabricated and tested a number of joint reinforcement specimens and has fabricated full scale graphite/epoxy panels for B-1 canards with joint reinforcements. Technical reports and test data were obtained from both divisions pertaining to their graphite/epoxy tasks in general and the joint reinforcement designs in particular. The conclusions drawn from a review of the survey are that for highly loaded joints (>2,000 lb/in.) metal reinforcement can provide an efficient joint and titanium is the metal commonly used for compatible coefficient of thermal expansion with graphite/epoxy. In addition, shim type joints are more effective for the required application than either step or scarf type joints.

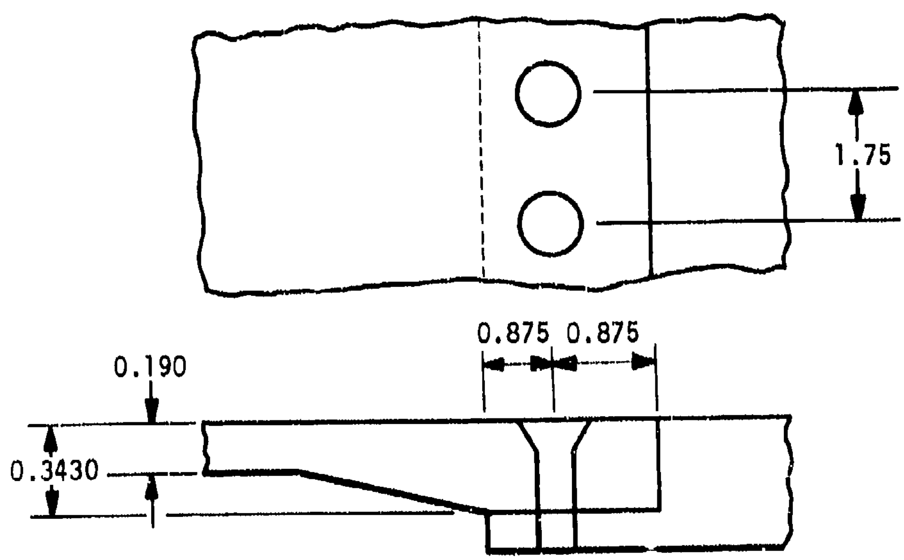
An independent analysis was then conducted to evaluate non-metal and metal shim type reinforcement designs and also to determine the most efficient bolt pattern for transferring loads from the reinforced joint to the adjacent missile section. The analysis was conducted for a maximum design load of 5100 $\frac{lb}{in.}$ which represents the combined effect of compressive load and bending moment at the large end of the shell.

5.1 Bolt Pattern Design

An analysis was conducted to determine a bolt pattern which would be capable of transferring the design loads using 100° countersunk head bolts and would result in the lightest weight and most compact reinforced joint design. It was determined that the design loads could be transferred through either a single row of 0.4375 inch bolts or through a staggered double row of 0.25 inch bolts. However, the lightest weight reinforced joint design is achieved using the staggered double row of bolts. Bolt spacing requirements for the staggered double row of bolts result in a load of 2550 lbs. per bolt requiring a total titanium shim thickness of 0.0765 inch and an overlap of 1.866 inches with the adjacent missile section; bolt spacing requirements for the single row of bolts result in loads of 8925 lbs. per bolt requiring a total titanium shim thickness of 0.1530 inch and an overlap of 1.75 inches. This is illustrated in Figure 5-1. Although the overlap for the double row of bolts is 7% greater than that for the single row of bolts, the total reinforced joint length is considerably less for the double row bolt design. In order to achieve a smooth transfer



STAGGERED DOUBLE ROW OF 0.25 IN COUNTERSUNK BOLTS FOR TITANIUM SHIM REINFORCEMENT DESIGN



SINGLE ROW OF 0.4375 IN. COUNTERSUNK BOLTS FOR TITANIUM SHIM REINFORCEMENT DESIGN

Figure 5.1. Alternative Bolt Patterns for Reinforced Splice Joint Design

of load from the graphite laminae to the reinforcing shims, the introduction of the shims into the graphite layup must be staggered. For a given individual shim thickness, the design using a double row of bolts requires only half the number of shims as one using a single row of bolts and therefore requires less length for shim introduction into the graphite layup. Since there are fewer shims and they are shorter in length for the design using a double row of bolts, this joint design is lighter and more compact.

The double row of bolts also allow a more uniform stress distribution in the reinforced joint since the bolts are closer together. In addition, the smaller bolts require less depth for their countersunk heads than do the larger bolts. This results in a more effective bearing region between the reinforcing shims and the bolts.

Based on the bolt pattern analysis, all reinforced shim designs that were considered incorporated a staggered double row of bolts for load transfer to adjacent missile sections.

5.2 Joint Reinforcement Design Comparison

Six shim type joint reinforcement designs were analyzed. These included three titanium reinforcement designs and three non-metallic reinforcement designs. The materials considered for each joint reinforcement design were as follows:

Designs 1, 2, and 3 - Titanium Shims
Material: Ti-13V-11Cr-3Al (or equivalent)
Reference: MIL Handbook 5B, August 1974

Design 4 - High Strength Graphite/Epoxy Layers
Material: NARMCO 5206, Type II [0/±45/90] Family
Reference: Advanced Composites Design Guide, January 1973

Design 5 - Fiberglass/Epoxy Cloth Layers
Material: Bloomingdale BP911/7781 cloth
Reference: MIL Handbook 17A, January 1971

Design 6 - Kevlar/Epoxy Cloth Layers
Material: Style 181 "Kevlar" 49 Aramid cloth
Reference: "Kevlar" 49 Data Manual - I. E. DuPont Company

Table 5-1 shows a summary of the analysis of the six reinforced joint configurations. The three titanium reinforcement designs (Designs 1, 2, and 3) all resulted in joints of reasonable thickness and are shown in Appendix B. The three non-metallic reinforcement designs (Designs 4, 5, and 6) all resulted in excessively thick joints since the reinforcing

Table 5-I. Summary of Reinforced Joint Configuration Analyses

Design	Bearing Strength (psi)	E (psi x 10^6)	Design Load (lb/in.)	Safety Factor	Required Reinforcement Thickness (in.)	Layer Thickness (in.)	No. of Layers Required	Total Joint Thickness (in.)
1	200	14.5	5100	1.5	.0765	.0072	11	0.269
2	200	14.5	5100	1.5	.0765	.004	20	0.270
3	200	14.5	5100	1.5	.0765	.005	18	0.190*
4	67	7.0	5100	1.5	.2284	.0065	36	0.424
5	70	3.9	5100	1.5	.2186	.0093	24	0.413
6	25	4.5	5100	1.5	.6120	.009	68	0.802

* GY70/934 layers butt up to titanium shims rather than continue to end of joint.

materials have low bearing strengths. In addition, the titanium reinforcements produce less eccentric loading at the splice joints than the non-metallic reinforcements because of the smaller total titanium reinforcement thickness required. This smaller titanium reinforcment thickness also results in fewer reinforcement shims being required and because of the staggered introduction of these shims into the graphite layup this results in a shorter reinforced joint design than with the use of non-metallic shims. The high modulus of elasticity of titanium compared to that of any of the non-metals considered also results in stiffer splice joints with the use of titanium reinforcements.

Based on the above conclusions, it was determined that the three reinforcement designs to be fabricated and tested in this program should be Designs 1, 2, and 3. Detailed designs are shown in Drawing 48126, Revision A in Appendix C. Evaluation of these three titanium reinforcement joint configurations with respect to design, fabrication and testing will determine which design is most effective for the required splice joint application.

Only a portion of the planned fabrication and testing was accomplished under the contractual effort covered by this report. Four Design 1 type joint reinforced frusta were fabricated by General Dynamics, Convair Division, San Diego, California. These four frusta were evaluated in shock tests, and in static tests as described in Section 6.0 and in Appendix E.

6.0 TESTING OF JOINT REINFORCED SPECIMENS

6.1 Test Objectives and Procedures

Structural tests were performed to evaluate the load carrying capabilities of the joint reinforcement of Design 1 of the conical shell (Appendix C). Loads were introduced to the splice joints through the countersunk screws. Dynamic loads simulating separation shock constitute one of the test conditions. Combined loads simulating the maximum loading conditions were applied as the static load condition.

Four joint reinforcement shells, fabricated by General Dynamics, Convair Division, San Diego, California, were tested. The double rows of 100° countersunk holes for 1/4 inch screws were machined by the Engineering Prototype Laboratory (EPL) of Martin Marietta. A drill fixture was built specifically for machining GY70/epoxy shells. The shell is held closely between an inner and outer fixture to prevent graphite fiber break-out during drilling. No particular problem was encountered in machining the GY70/epoxy shell reinforced with titanium shims, if relatively low drill speed is maintained.

Figure 6-1 shows unit 01R of the reinforced frustum with the countersunk holes machined. Figure 6-2 is an end view of unit 01R depicting the breaks in the titanium shims in each layer and the interleaving of titanium shims and graphite layers.

6.1.1 Loading Conditions

A total of 4 tests were conducted in the Martin Marietta Structures Test Laboratory on 4 joint reinforced frusta. The tests consists of 2 shock tests and 2 static tests of combined loads. The detailed test procedures are included in Appendix E.

The loading condition for each of the reinforced frusta is described in the following paragraphs.

Test 1A (Reinforced Frustum 01R) - Shock Loading

This loading condition simulating the second stage ignition shock was an axial loading generated by a shock load machine (SM-1000). The test frustum was bolted to a test fixture through the 48 countersunk holes. The test fixture was fastened to the shock machine at its base. The smaller end of the frustum was free. The test fixture was designed such that the loads were transmitted to the frustum through the 48 radial screws. Figure 6-3 shows the frustum and test fixture in relation to the shock machine.

The shock machine table to which the test fixture is bolted in supported by four hydraulic pistons. The table is driven down by the hydraulic pistons against the anvil to produce the shock that is measured by an accelerometer mounted on the table. The shock level produced is dependent upon the drop height, charge pressure of the hydraulic system, and the impacting material. The input shock is transformed into a shock spectrum by means of a spectrum analyzer.

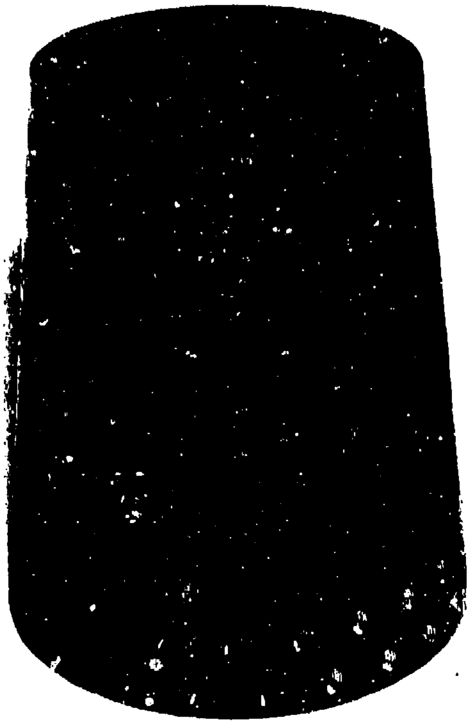


Figure 6-1. Reinforced Frustum with Countersunk Holes, Unit 01R

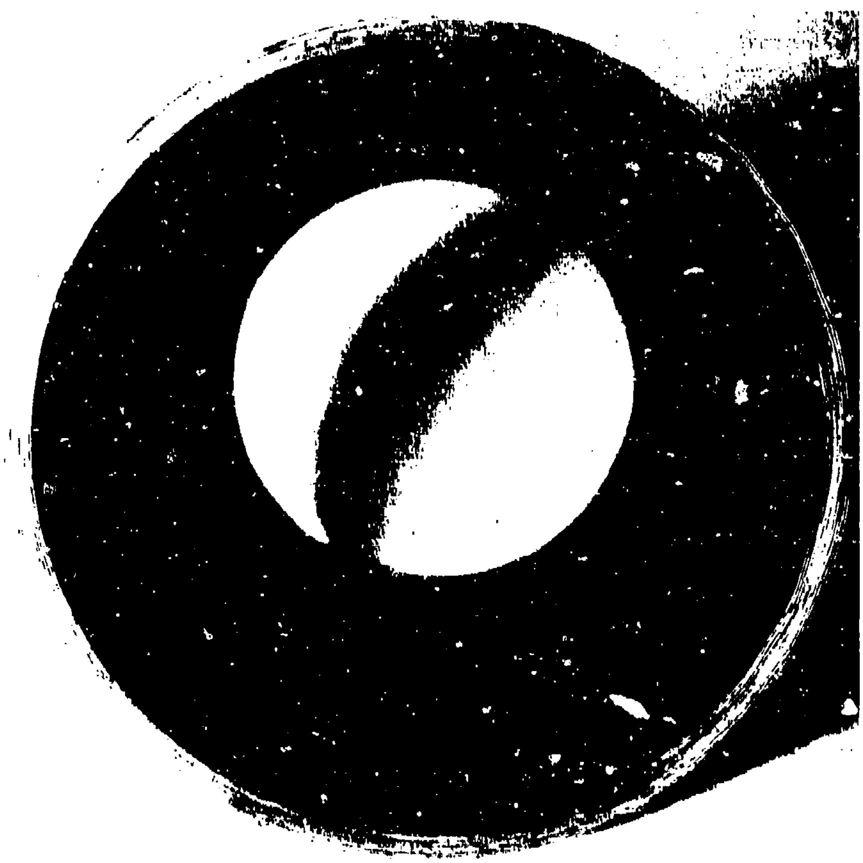


Figure 6-2. Titanium Shim Reinforcements, Unit 01R

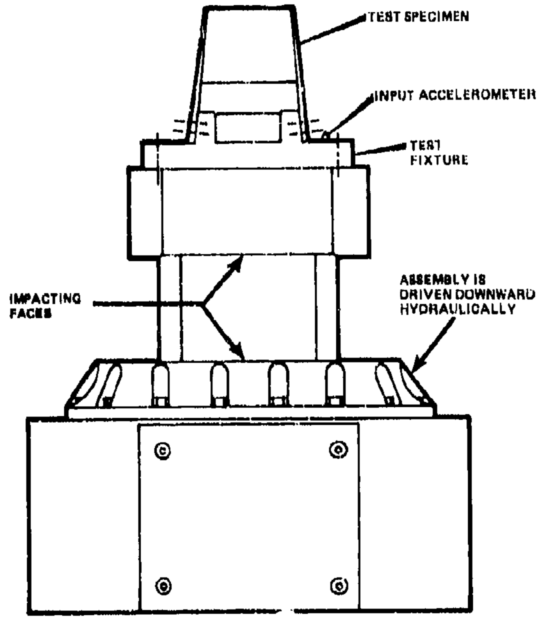


Figure 6-3. SM-1000 Shock Machine with Frustum in Test Mode

To determine the capability of the specimen to withstand the shock loading, the level of the shock load was increased by increments until the specimen failed. The shock spectra were determined from ATI system requirements. The shock spectra, which the test attempted to simulate, are shown in Appendix E. The actual spectra measured during the test are shown in Appendix F.

Twelve axial type strain gages were installed on the specimen to record the stress levels under shock loads. The location of the strain gages are shown in Appendix E. Shell unit 01R was used for this test.

Test 2A (Reinforced Frustum 02R) - Shock Loading

Shell unit 02R was used for the shock test. This test was a repeat of Test 1A in order to obtain a second data point for correlation. The instrumentations were the same as in Test 1A. Refer to Appendix E for details.

Test 3A (Reinforced Frustum 03R) - Combined Static Loading

Shell 03R was tested under combined static loads to verify the reinforced joint design. The loads were applied by hydraulic jacks monitored by load cell readings. Shear loads, bending moment and axial load were applied simultaneously at increments until failure occurred.

Sixteen axial type strain gages were installed on the shell specimen. DCDT's were located to measure the true deflection of the specimen under load. The location of the instrumentation are shown in Appendix E.

Test 4A (Reinforced Frustum 04R) - Static Shear/Bond Test

Shell 04R was tested in simple cantilevered loading which subjected the splice joints to equal tension and compression. Sixteen axial type strain gages were installed on the shell specimen.

DCDT's were located to determine the shell deflections. The instrumentations and detailed test procedures are shown in Appendix E.

6.2 Test Results on Frusta With Joint Reinforcements

Frustum 01R was shock tested in accordance with the test procedures given in Appendix E. During the calibration runs, it was established that two types of impacting materials were required to place on the impact bed of the SM-1000 shock machine in order to obtain the range of 1000 g's to 42,000 g's in the shock spectrum. In the range of 1000 g's to 11,000 g's (low level) one inch thick foam rubber was placed between the impacting faces of the shock machine and the charge pressure was varied from 15 psi to 60 psi. In the range of 9,300 g's to 42,000 g's (high level), 1/16 inch rubber pad was placed as the impacting material and the charge pressure was varied from 10 psi to 60 psi. In all cases maximum drop height of 4 feet was set. Figure 6-4 is a view of the SM-1000 shock machine with the test specimen installed in place. Figure 6-5 shows all the equipment used for the shock test. From right to left are the test control console, oscillograph, spectrum analyzer, tape recorder and print-out equipment.

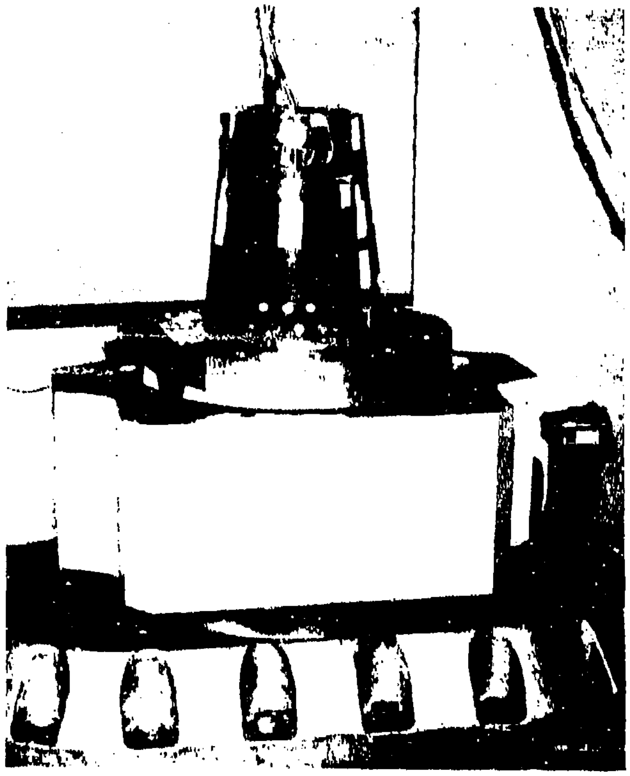


Figure 6-4. SM-1000 Shock Machine with Frustum in Place

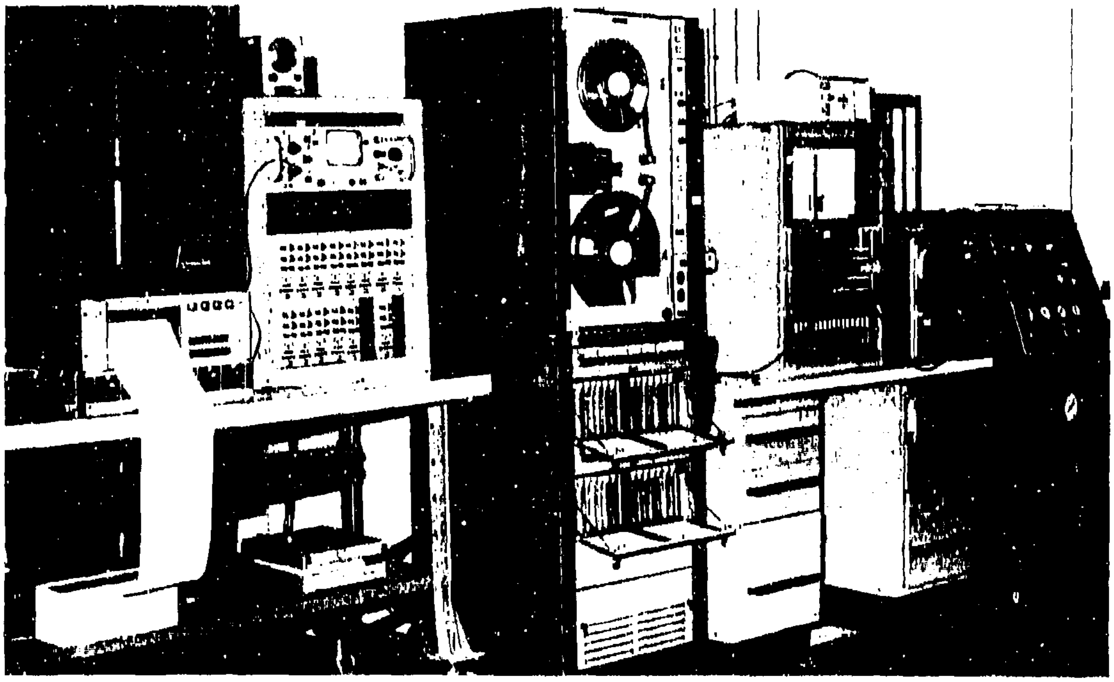


Figure 6-5. Shock Testing Equipment

On unit 01R surface crack was developed extending longitudinally from the countersunk hole to the edge of the frustum at input shock of 14,000 g's corresponding to peak acceleration of 25,000 g's on the shock spectrum. The part was able to sustain the maximum shock level without any further damage. The surface crack around one fastener had no significant effect on joint strength.

On unit 02R, a similar surface crack was developed at an input shock of 9500 g's corresponding to peak acceleration of 22,000 g's on the shock spectrum. No further damage occurred at higher shock levels.

Unit 03R tested under simultaneous static loading of shear, bending, axial load and lateral pressure failed at 200 percent DLL. Failure occurred at the top of the smaller end extending at approximately 45° down toward the larger end. The splice joint was still capable of carrying loads, although the holes were elongated due to plastic bearing deformation. Analysis show that the ultimate bearing stress is reached at 162% of DLL.

Unit 04R tested under a single static shear load at 2,000 lbs. increment failed at 34,000 lbs. The failure occurred near the smaller end. Analysis predicted local interlaminar shear failure at the forward end at 3,000 lbs. and joint failure in net section tension at 36,300 lbs. It is significant to note that in the two tests the joints are stronger than the basic shell and are capable of plastic deformation and load transfer to the GY70/Epoxy laminates above the design load level.

6.3 Data Analysis and Correlation - Joint Reinforcement Frusta

6.3.1 Shock Tests

All test data, strain readings and acceleration measurements, were recorded on magnetic tapes during the test run and were subsequently printed on oscillograph paper as a function of time. The input shock is transformed into a shock spectrum by means of a spectrum analyzer. The shock spectrum is plotted as an output on the automatic plotter. The shock spectra for units 01R and 02R for each of the shock levels are included in Appendix F. For unit 01R, test runs 1 and 2 are not included; for unit 02R test run 1 is not included. These initial shock levels were too low for the analyzer to register and function, therefore, the shock spectra were not given.

Calibration runs were conducted prior to the installation of the specimen on the SM-1000 shock machine in order to match the input shock level to the shock spectra specified in the test plan. Close matching of the peak shock levels was accomplished.

The peak values of acceleration and strain measurements are tabulated in Tables 6-I and 6-II for unit 01R and 02R respectively. The input shock levels are the measurements taken from the accelerometer mounted on the test fixture. The response peak g's are the maximum values taken from the shock spectra. The test runs of low shock levels are not included in the tabulations since they are of no significance in the data analysis.

Strain gages (SG) 1 through 10, located 4.37 inches from the base, theorectically should have the same strain value for a given shock level. The actual recorded strains vary as can be observed from Tables 6-I and 6-II. The two probable sources of this variation are: 1) The splice screws do not have equal degree of bearing around the shell causing non-uniform strain distribution; 2) The variation of longitudinal modulus of elasticity of the shell around the circumference, resulting from the gore pattern in the surface layer, would cause similar variations in strain distributions. Strain readings at S.G. 11 are expected to be higher than those of S.G. 1-10 due to the higher inertia loading at that location which is 2.87 inches from the base, and the test data are in agreement. Similarly, data from S.G. 12 show lower strains as expected, since it is located 1 inch from the top end reflecting a small inertia loading.

At each strain gage location, strain was calculated from the peak response g's recorded during the test, the mass of the shell above the location and the elastic modulus of the graphite/epoxy shell. The comparisons of calculated strains from the shock tests are shown in Tables 6-III and 6-IV for frustum units 01R and 02R respectively. The dynamic or the magnification factors can be determined by dividing the measured strain by the calculated strain. The magnification factors are listed in Tables 6-III and 6-IV. For half-sine shock pulse, the magnification factor has a theoretical maximum of 1.77 for a single vibration mode response. The observed values as high as 2.50 indicate dynamic response contributions from higher structural modes. The large variation in the factor is due to discrepancies in the strain distibution as discussed earlier. The maximum strain was 800 μ in/in. which is safely below the allowable strain for GY70/Epoxy of 2,100 μ in/in.

TABLE 6-I

Test Data - Test No. 1A - Shock Test

Run No.	Input Shock g's	Response Peak g's	Str. Gage No. 1 μin/in	Str. Gage No. 2 μin/in	Str. Gage No. 3 μin/in	Str. Gage No. 4 μin/in	Str. Gage No. 5 μin/in	Str. Gage No. 6 μin/in	Str. Gage No. 7 μin/in	Str. Gage No. 8 μin/in	Str. Gage No. 9 μin/in	Str. Gage No. 10 μin/in	Str. Gage No. 11 μin/in	Str. Gage No. 12 μin/in
10	4,500	9,300	- 50	-100	-300	- 90	-100	-200	-100	-170	-150	-100	- 70	-0-
11	11,000	24,000	-140	-100	-580	-400	-250	-220	-130	-300	-400	-220	-220	- 50
12	14,000	27,000	-200	-250	-450	-400	-300	-400	-280	-350	-500	-300	-380	-100
13	16,500	33,000	-370	-350	-500	-500	-200	-450	-400	-500	-550	-320	-520	-100
14	18,000	35,000	-450	-450	-520	-600	-210	-500	-600	-650	-600	-360	-600	-150
15	19,000	41,000	-450	-400	-550	-680	-420	-620	-450	-450	-800	-570	-600	-150

TABLE 6-II

Test Data - Test No. 2A - Shock Test

Run No.	Input Shock g's	Response Peak g's	Str. Gage No. 1 μin/in	Str. Gage No. 2 μin/in	Str. Gage No. 3 μin/in	Str. Gage No. 4 μin/in	Str. Gage No. 5 μin/in	Str. Gage No. 6 μin/in	Str. Gage No. 7 μin/in	Str. Gage No. 8 μin/in	Str. Gage No. 9 μin/in	Str. Gage No. 10 μin/in	Str. Gage No. 11 μin/in	Str. Gage No. 12 μin/in
8A	6,500	12,500	-100	-130	-150	- 80	- 80	- 80	- 80	-100	-100	- 30 (+100)	-100	- 0
9	9,500	21,000	-250	-250	-180	-200	-250	-200	-180	-200	-200	-200	-320	- 50
10	13,000	26,500	-360	-300	-180	-200	-300	-300	-400	-300	-300	-230	-480	- 50
11	15,000	32,000	-500	-400	-200	-300	-400	-450	-550	-300	-300	-400	-620	-120
12	17,000	34,000	-550	-400	-200	-350	-500	-550	-650	-300	-200	-500	-680	-120
13	17,500	38,000	-500	-400	-350	-450	-450	-350	-350	-500	-500	-250	-420	- 80
14	18,000	38,000	-500	-400	-330	-420	-550	-450	-400	-480	-500	-370	-580	-100
15	17,500	37,000	-480	-420	-380	-400	-550	-420	-500	-450	-600	-380	-550	-100

TABLE 6-III

Strain Data (Test versus Calculation), Unit 01R

Run No.	Avg. Strain of Gages 1 - 10 (Test) μ in/in	Strain (Calc.) μ in/in	Mag. Factor	Strain S.G. 11 (Test) μ in/in	Strain (Calc.) μ in/in	Mag. Factor	Avg. Strain S.G. 12 μ in/in	Strain Calc. μ in/in	Mag. Factor
10	-136	- 56	2.43	- 70	- 63	1.11	0	- 12	-
11	-274	-189	1.45	-220	-213	1.03	- 50	- 42	1.19
12	-343	-222	1.55	- 380	-251	1.52	-100	- 49	2.04
13	-414	-244	1.70	-520	-277	1.88	-100	- 54	1.85
14	-488	-266	1.83	-600	-300	2.0	-150	- 60	2.50
15	-539	-390	1.38	-600	-438	1.37	-150	- 86	1.75

Input Shocks:		
	10	4,500 g's
	11	11,000
	12	14,000
	13	16,500
	14	18,000
	15	19,000

TABLE 6-IV

Strain Data (Test versus Calculation), Unit 02R

Run No.	Avg. Strain of Gages 1 - 10 (Test) µ in/in	Strain (Calc.) µ in/in	Mag. Factor	Strain S.G. 11 (Test) µ in/in	Strain (Calc) µ in/in	Mag. Factor	Strain S.G. 12 (Test) µ in/in	Strain (Calc) µ in/in	Mag. Factor
8A	- 93	- 73	1.19	-100	- 88	1.14	0	-17.2	-
9	-211	-167	1.26	-320	-189	1.09	- 50	-36.0	1.39
10	-287	-200	1.44	-480	-227	2.11	- 50	-44.4	1.13
11	-380	-244	1.56	-620	-278	2.23	-120	-54.1	2.22
12	-420	-278	1.51	-680	-315	2.16	-120	-61.5	1.95
13	-410	-278	1.47	-420	-315	1.34	- 80	-61.5	1.30
14	-440	-334	1.32	-580	-379	1.53	-100	-74	1.35
15	-448	-267	1.68	-550	-303	1.81	-100	-59	1.09

Input Shocks:		
	8A	6,500 g's
	9	9,500
	10	13,000
	11	15,000
	12	17,000
	13	17,500
	14	18,000
	15	17,500

6.3.2 Combined Static Load Tests

Sixteen axial type strain gages were installed to measure the strains at two sections of the shell. Four gages were located at the basic shell section approximately half way between the ends. Twelve other gages were located at the reinforced transition section near the countersunk fasteners. The plots of load vs. strains are shown in Figures 6-6 through 6-9.

In Figure 6-6, strain data for gages 1, 2, 3 and 4 show that the slopes of load/strain are essentially linear up to 160% Design Limit Load (D.L.L.) and some local failures initiated at that point to cause the changes of slope of the curves. Similar structural behavior was observed on the tension side in gages 9, 10, 11 and 12 of Figure 6-7. Some bending through the thickness was indicated by the spread of the strains of the inner and outer surfaces. Gages 6, 7, 14 and 15 in Figure 6-8 located at the theoretical neutral axis of the section indicated relatively small strains as expected. In Figure 6-9 the strain measurements of gages 8 and 16 have opposite signs when theoretically they should be of equal sign under the symmetric applied loads. However, in this case, the axial compression load did not induce uniformly distributed axial strain, since the splice screws did not have equal fit in the holes. It is postulated in the region of gage 8 high axial compressive strain produced the high tensile strain through poisson ratio effect, whereas in the region of gage 16 low axial compressive strain was present and the strap radial load predominated the compressive strain in gage 16.

Four direct current deflection transducers (DCDT) were installed to measure the load/deflection of the reinforced specimen. One of the DCDT's was placed on the graphite shell at the free end to measure the transverse movement. The other three DCDT's were located on the mounting fixture - two for longitudinal displacements and one for transverse displacement. The net deflection of the shell at the free end was computed from the displacement data of the four DCDT's. The load/deflection plot is shown in Figure 6-10. It is essentially linear to 160% of D.L.L. Local fractures and plastic deformation of bolt holes caused the break at 160% D.L.L.

6.3.3 Shear/Bending Static Test

The number of strain gages and DCDT's and their locations with respect to the test specimen are the same as those for the combined load test specimen. The load/strain data plots are shown in Figures 6-11 through 6-14.

Gages 1, 2, 3 and 4 in Figure 6-11 are under compressive strains from the bending loads. Gages 1 and 2 show uniform strain through the section of the basic shell, whereas gages 3 and 4 located in the reinforced transition section indicate bending exists through the thickness. This bending stress near the splice screws will produce bending or cocking of the countersunk screws.

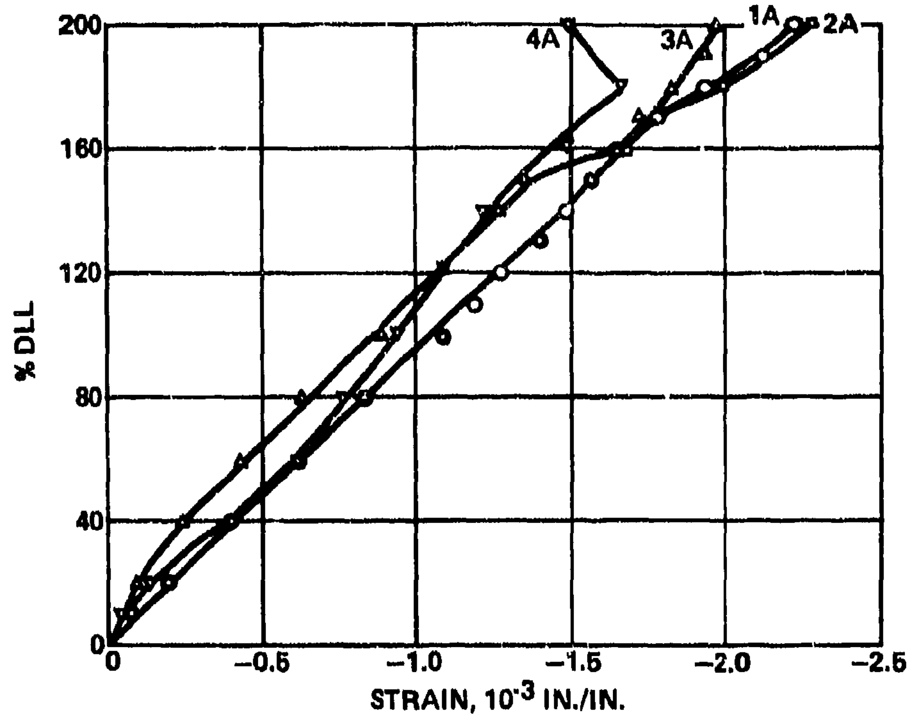


Figure 6-6. Load/Strain Plot - Combined Loads Test 3A, Gages 1 through 4

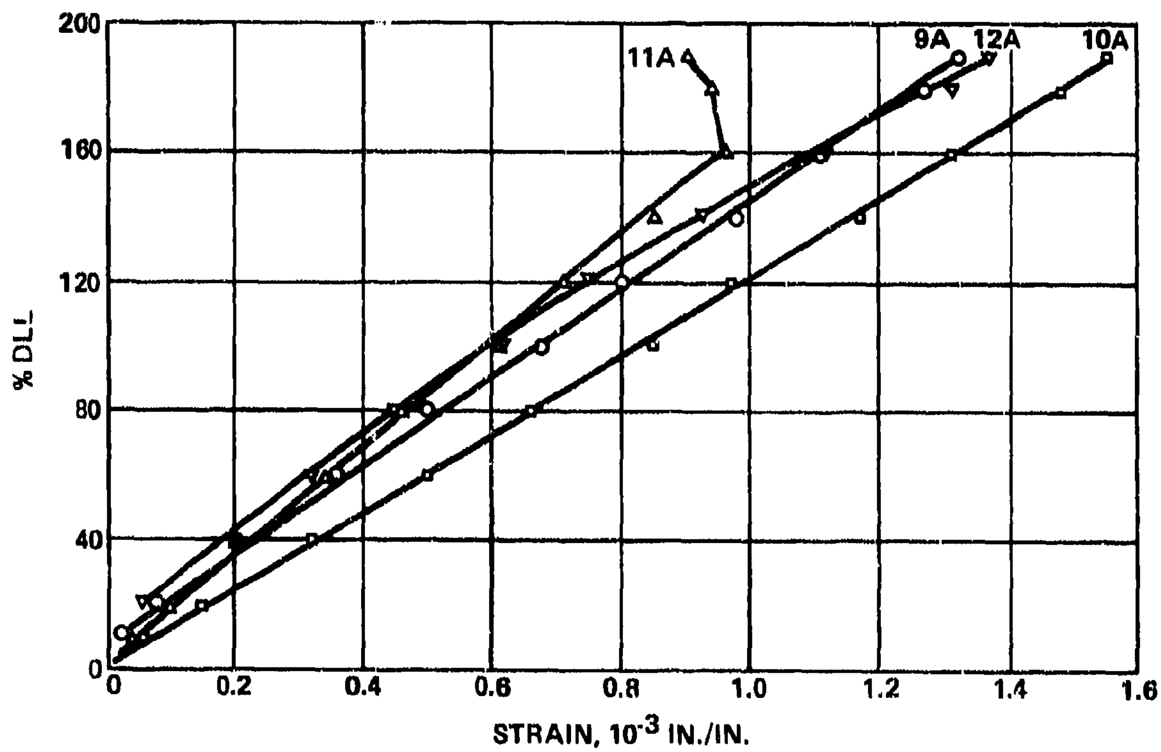


Figure 6-7. Load/Strain Plot - Combined Loads Test 3A, Gages 9 through 12

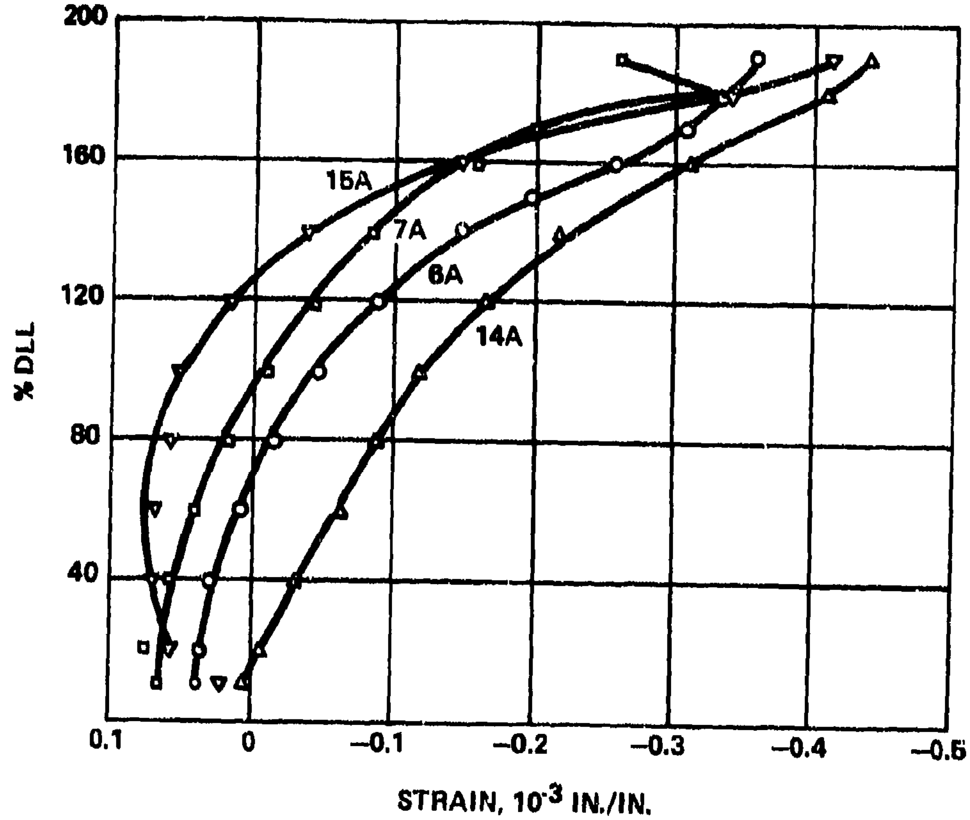


Figure 6-8. Load/Strain Plot - Combined Loads - Test 3A, Gages 6, 7, 14, and 15

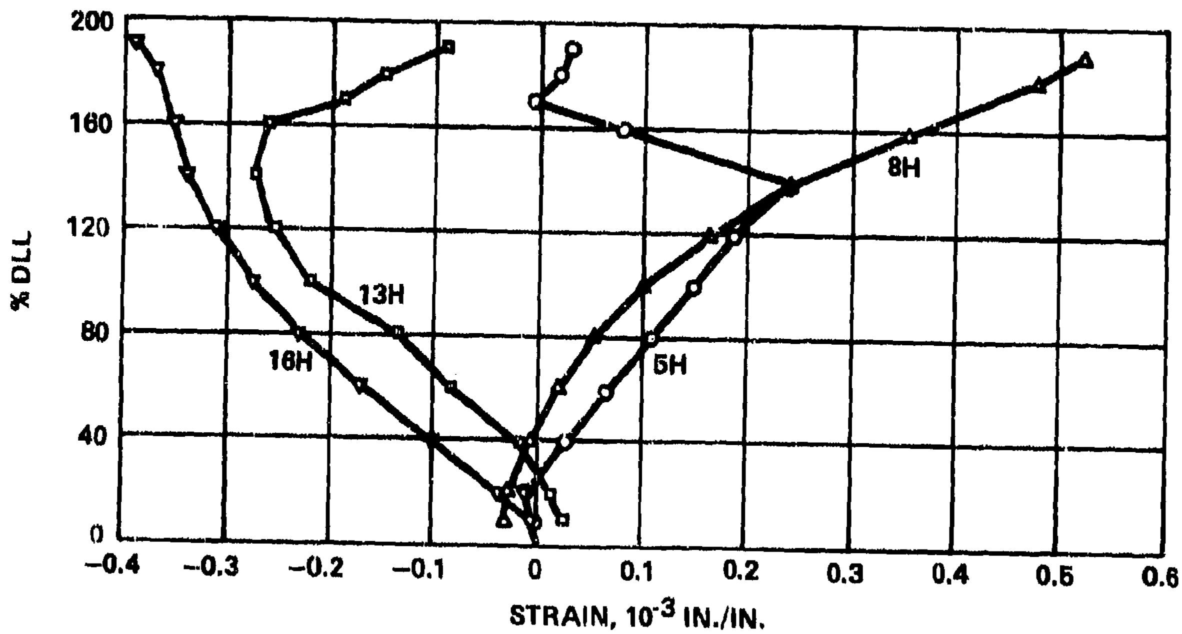


Figure 6-9. Load/Strain Plot - Combined Loads - Test 3A, Gages 5, 8, 13, and 16

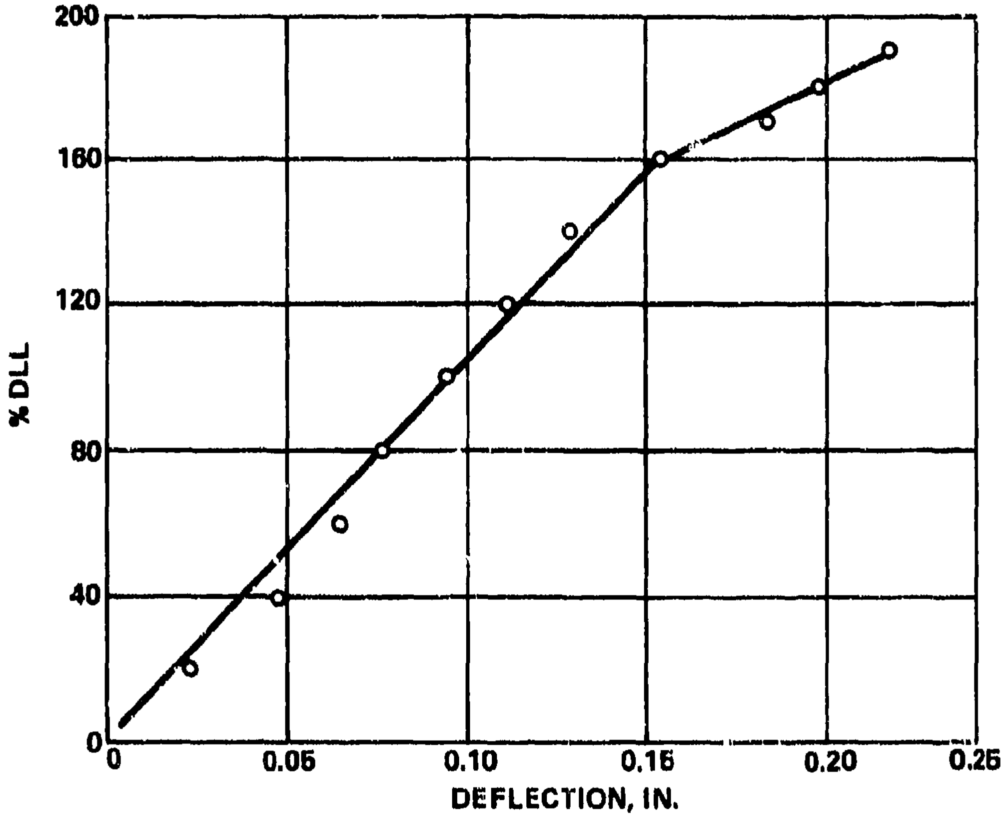


Figure 6-10. Load Deflection - Combined Loads - Test 3A

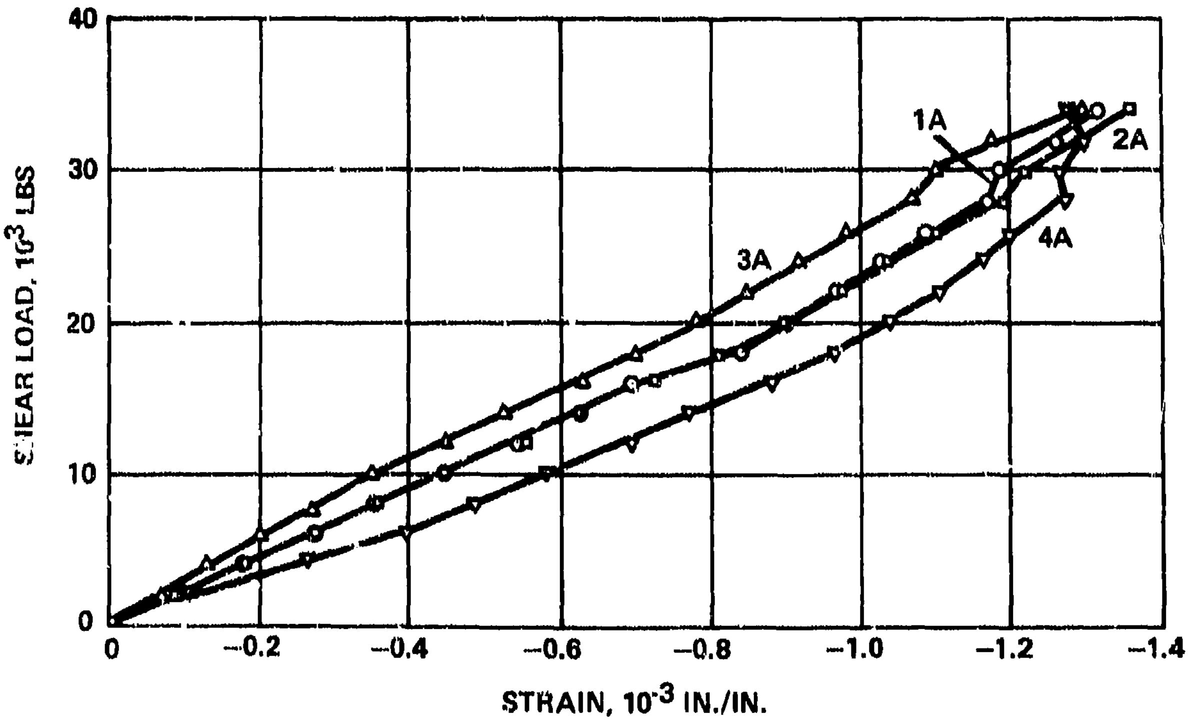


Figure 6-11. Load/Strain Plot - Shear/Bending -
Test 4A, Gages 1 through 4

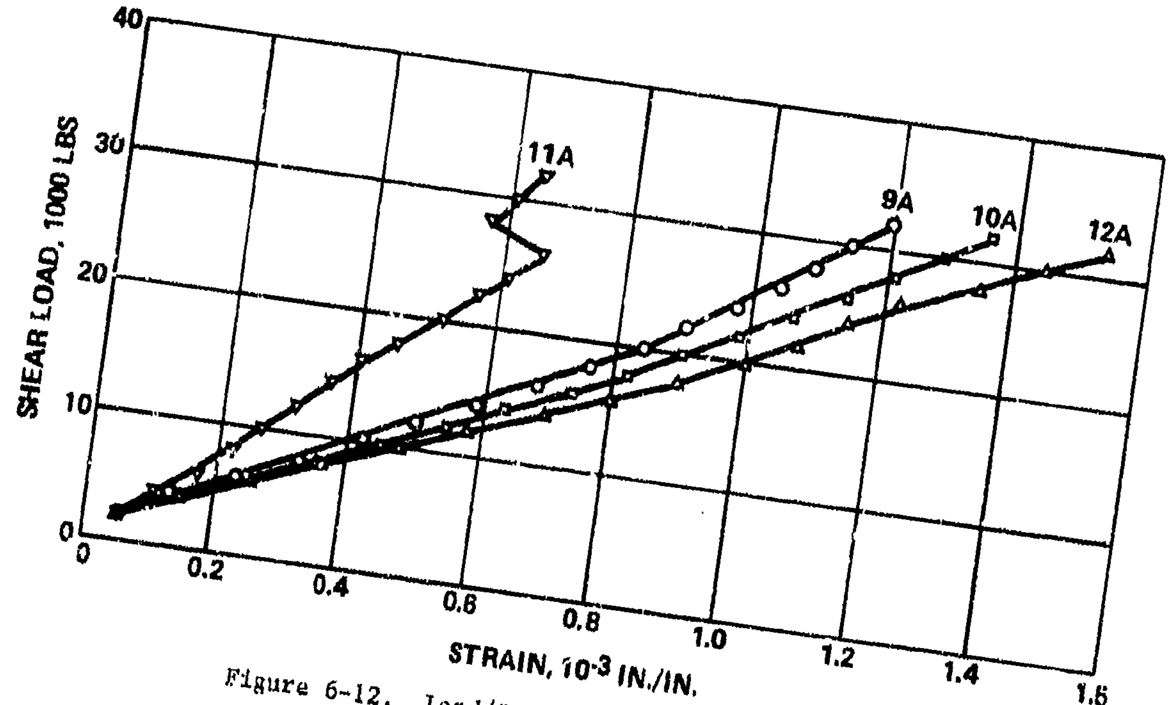


Figure 6-12. Load/Strain Plot - Shear/Bending, Gages 9 through 12

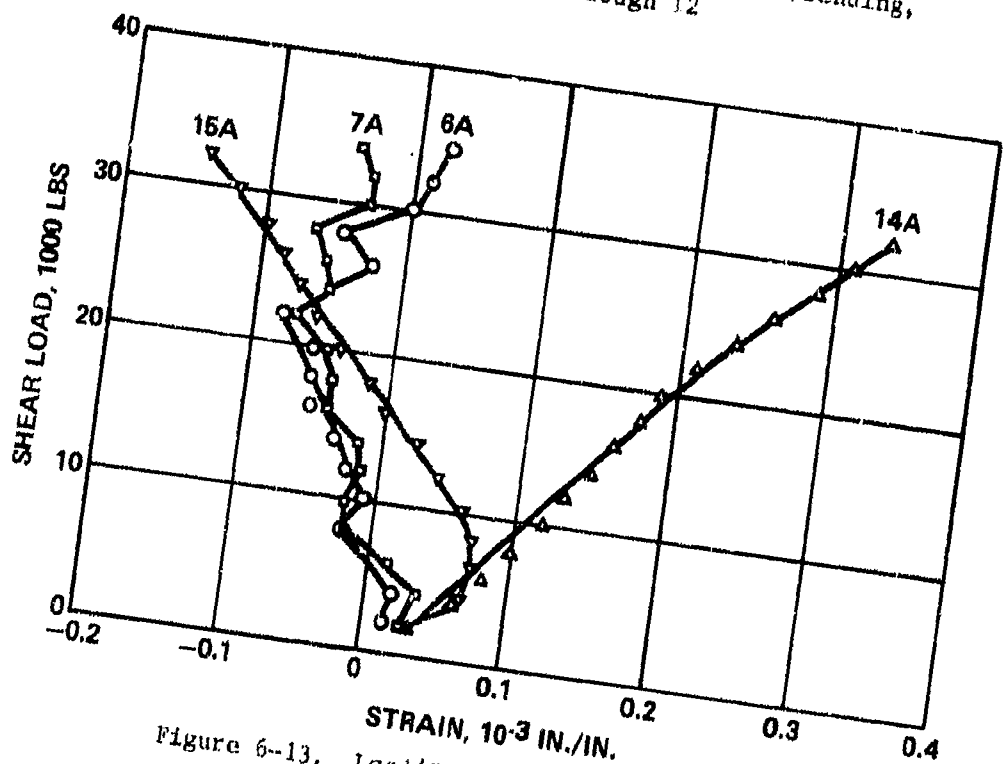


Figure 6-13. Load/Strain Plot - Shear/Bending, Gages 6, 7, 14, and 15

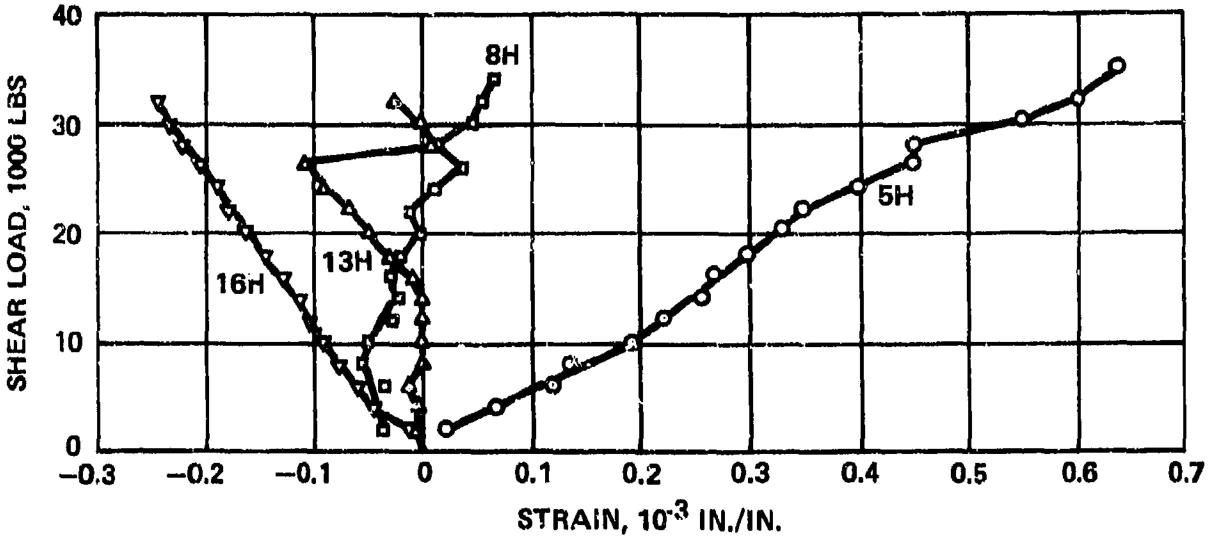


Figure 6-14. Load/Strain Plot - Shear/Bending, Gages 5, 8, 13, and 16

Gages 9, 10, 11 and 12 on the tension side show the same trend as the compressive strains of gages 1, 2, 3 and 4 with the exception that some local failure near the outside surface introduced a discontinuity in gage 11.

Gages 6, 7, 14 and 15 located at the neutral axis of the section were expected to register low strains; gages 6 and 7 did have low strains recorded. However, gages 14 and 15 recorded relatively high strains and had opposite signs. After careful examination of the tested shell, the strain discrepancies can be explained by the fact that the bolts near gages 14 and 15 had loose fit in the holes causing large rotation of the bolts. The countersunk head induced compression in the outside skin (S.G. 15) while the shank of the bolt reacted the tension. Note that gages 6 and 7 are affected to a less degree.

Gages 5, 8 and 13 gave transverse strains that arise from the Poisson's ratio effect. Gage 16 did not seem to be the result of Poisson effect. No positive explanation can be given for its behavior. It can be assumed that the transverse compressive strain is a result of screw head bearing against the surface layer.

The load deflection curve of the frustum is shown in Figure 6-15. The 'shell + joint' plot was calculated directly from the DCDT data taken during the tests. The deflection was taken transverse to the axis of the shell at 1.9 inches from the small end. To determine the contribution to the deflection from the splice joint, the shell deflection was calculated using the known elastic properties of the GY70/Epoxy laminate and was deducted from the overall deflection. The joint deflection data was used to compute the joint stiffness in terms of $\frac{M}{\theta}$ where M is the applied moment at the splice joint in in-lbs. and θ is the joint rotation in radian. Figure 6-16 shows a joint rotational stiffness of 0.26 x 10^8 in-lb/radian, which is considered to be an acceptable stiffness based on the advanced interceptor dynamic response study.

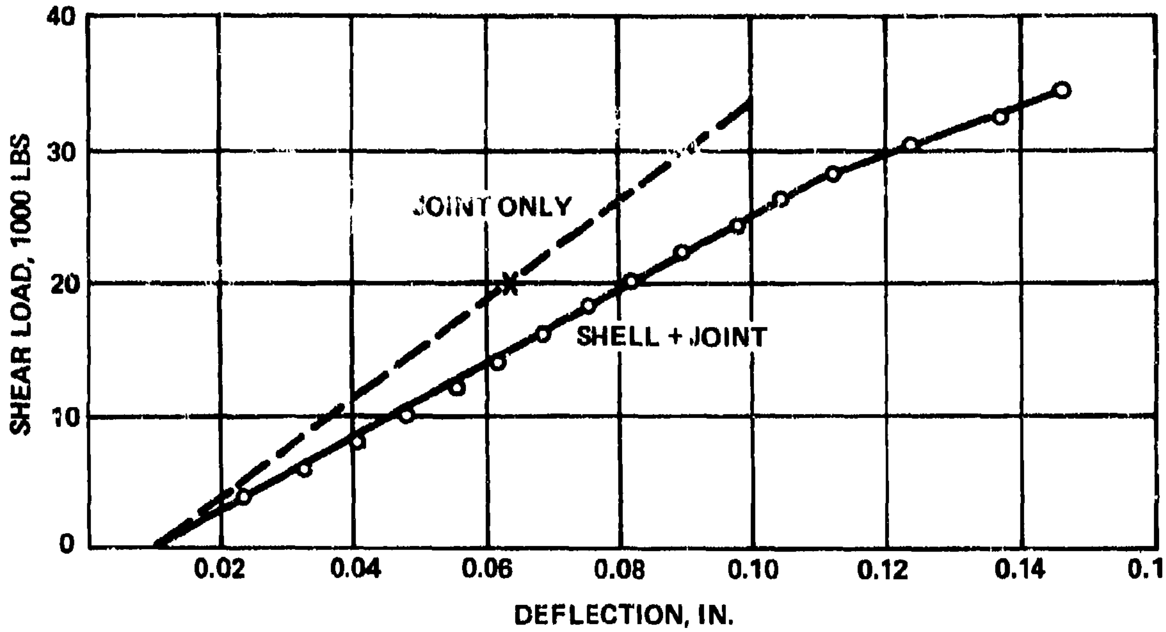


Figure 6-15 Load/Deflection - Shear/Bending

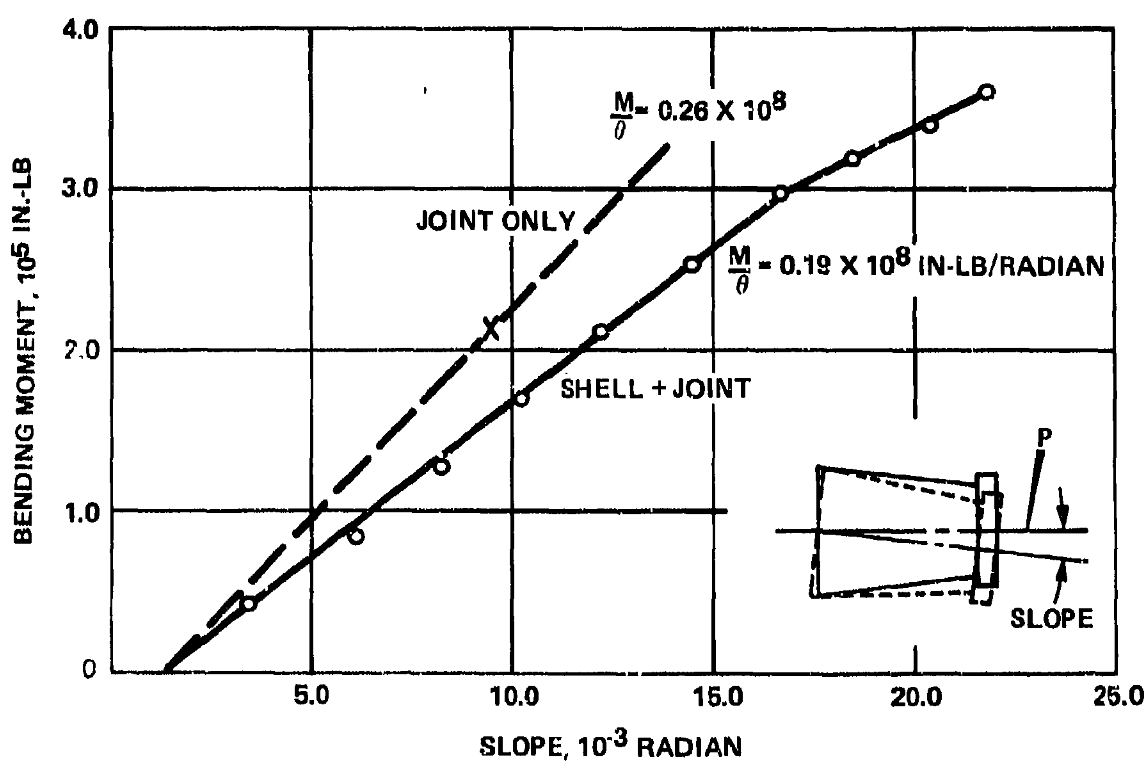


Figure 6-16 Joint Rotational Stiffness

7.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the structural testing of the half-scale frusta, the following conclusions can be drawn:

1 A subscale conical shell of GY70/Fiberite 934 ultra high modulus composite material can be designed and fabricated based on load and boundary conditions for the Advanced Terminal Interceptor with analytically predictable load carrying capability. This verifies the validity of the analytical methods used.

2 A static load interaction curve for conical frusta has been experimentally defined for various load paths and combinations of compression, shear and bending moment loads showing good correlation with analytical predictions. The reasonably consistent behavior of the test points are indicative of a uniform and good quality manufacturing process.

3 Seams existing in the conical shells due to the gore pattern layup have no apparent adverse effects on the strength or stiffness of the shell.

4 The axial compression tests on the frusta confirm a nonlinear stress/strain relationship exhibited in the test data of flat compression test coupons made from GY70/Epoxy laminate.

5 For axial compression, test data correlate well with analytical results when secant modulus from the test is substituted in the analysis.

6 All tests, except for the two axial compression tests, have shown localized failures in the specimens as indicated by the discontinuities in the strain gage data prior to the ultimate failure. It is postulated that the localized failures were caused by microcracks, high locked-in stresses or flaws in the fabricated shells.

7 GY70/Fiberite 934 laminated shells can carry substantially higher loads after the initiation of local failures. Redistribution of stresses took place after initial failure and allowed the shells to resist more loads until the ultimate failure.

8 Most of the initial failures occurred on the tension side of the shell. This would indicate the presence of microcracks or flaws which would produce high stress concentration under tension.

9 The lateral deflection calculations are conservative in comparison to the test measurements. However, the overall data correlation is considered good for the ultra high modulus composite shell.

10 It is recommended that in the follow-on program at least one conical shell be fabricated for the purpose of determining the extent of microcracks, voids or other flaws which might exist in the laminates.

11 GY70/Fiberite 934 laminated shell and its reinforced joint with titanium shims will withstand shock levels generated by stage separation shock.

12 Under the half sine shock pulse, the dynamic response factor in the GY70/epoxy structural shell approaches 2.0.

13 It is necessary to maintain low drill speed in the drilling and countersinking of GY70/titanium laminated composite. The laminated shell had to be backed in drilling to keep the graphite fibers from breaking out.

14 The revised layup sequence (48126B) effective units 03R and up should be shock tested to verify the laminate design. In addition, the next shock test should have a loose fit between the frustrum and its mounting fixture to determine the impact of splice joint tolerance. The units 01R and 02R tested had tight fit.

15 GY70/Fiberite 934 laminated shell with titanium reinforced splice joints will withstand 200% of D.L.L. Catastrophic failure occurred in the basic shell section. The splice holes were elongated but were still capable of carrying higher loads.

16 Under shear/bending loads, failure occurred at the small end of the graphite shell at a load of 34,000 lbs. The design load was 30,000 lbs. The splice joints had substantial deformation from plastic elongation of the bolt holes, but were capable of higher ultimate loads.

17 The joint rotational stiffness $(\frac{M}{\theta})$ of 0.26×10^8 in-lb/radian was considered to be an acceptable joint stiffness based on interceptor dynamic response studies.

18 Strain data strongly suggest that splice holes and screws should have close tolerance fit to achieve predictable strain distributions. Loose fit would induce high localized stresses and bending in the shell thickness.

REFERENCES

1. Development of Carbon Fiber-Resin Composite Materials for Advanced ABM Structures, Martin Marietta Corporation, Orlando Division, OR 12,919, Final Report, AMMRC Contract DAAG46-73-C-0052, September 1973.

2. Development of Carbon Fiber-Resin Composite Materials for Advanced ABM Structures, Martin Marietta Corporation, Orlando Division, Final Report, AMMRC Contract DAAG46-74-C-0127, September 1975.

3. Final Report - Advanced Terminal Interceptor Technology Program, Volume IV, Subsystem Trade Studies, OR 12,393, Martin Marietta Corporation, Orlando Division, April 1973.

4. Performance Tradeoff Studies, Special Task Report, No. 2, Defense Advanced Interceptor requirements and Configuration Analysis, OR 13,842, Martin Marietta Corporation, Orlando Division, September 1975.

5. A Point Stress Laminate Analysis and Design Optimization Code for Advanced Composite Structures, by Howard Kliger, Martin Marietta Orlando report No. ANA 10722729-003, November 1973.

6. SLADE - A finite element code developed by Sam Key of Sandia Corporation, Alburquerque, N. M.

7. TEXGAP - The Texas Grain Analysis Program, by R. S. Durham and E. B. Becker of University of Texas, August 1973.

APPENDIX A

REVISED MATERIAL SPECIFICATION

Material Specification

SUMMARY

A preliminary Material Specification detailing the Qualification and Acceptance criteria for Epoxy Preimpregnated Graphite Tows, Yarns, Tapes, Fabrics, and Mats has been written. This work was conducted under AMMRC Contract DAAG-46-74-C-0127, "Development of Carbon Fiber-Resin Composite Materials for Advanced ABM Structural Applications."

Revision B to this specification was made to update the requirements contained herein. The revision was based on information supplied by General Dynamics, Convair Division, San Diego, California, who has purchased GY70/Fiberite 934 prepreg tape with this specification under AMMRC contract DAAG 46-76-C-0008.

The following paragraphs and tables have been revised:

Paragraph 4.1
Paragraph 4.10.3.4
Paragraph 4.10.4.5(3)
Table I
Table III
Table IV
Table V(b)

1.0 SCOPE

1.1 Requirements

This specification establishes requirements for staged, impregnated, fibrous graphite materials in the following forms:
(1) yarns or tows
(2) multifilament collimated yarns or tows
(3) woven fabric
(4) chopped mat

1.2 Classification

1.2.1 Types. The graphite fibers are of high quality and are available in the following types:

Type I : High Modulus Fibers, surface treated.
Type II : High Tensile Strength Fibers, surface treated.
Type III: Intermediate Tensile Strength Fibers, surface treated.
Type IV : Ultra High Modulus Fibers made from single or double yarns, surface treated.
Type V : Ultra High Modulus Fibers in the form of a tape constructed from collimated yarns or tows, surface treated.

1.2.2 Class. The various types of graphite shall be supplied in the following forms or classes:

Class 1 - Continuous yarns, typically with 1/2 twist per foot and having up to 4000 filaments per yarn.
Class 2 - Continuous yarns, untwisted or twisted, having up to 4000 filaments per yarn.
Class 3 - Continuous tows, untwisted or twisted, consisting of more than 4000 filaments. Tows typically have between 10,000-150,000 filaments.
Class 4 - Continuous dry flat tape, typically three inches wide, consisting of 100-200 yarns per inch width.
Class 5 - Chopped Mat made from Class 1, 2, 3, or 4. Cut typically to one inch lengths and randomly oriented.
Class 6 - Fabrics woven to commercial standard forms from Class 1, 2, 3 or 4 fibers.

1.2.3 Resin Grades. Various grades of resin can be employed. If no Grade is specified, Grade A shall be supplied.

Grade A - An epoxy resin, typically but not limited to an amine catalized system, free of foreign materials, non-corrosive to metals and shall be capable of being molded at pressures of 110 pounds per square inch (psi) maximum to a fully thermoset state meeting the cured laminate properties of this specification.

1.3 Application. The impregnated material covered in this specification is intended for use as primary and secondary structure in aerospace systems.

NOTE: The commercial designation for both fiber and resin shall be specified on the purchase order.

2.0 APPLICABLE DOCUMENTS

The following documents of the issue in effect on date of invitation for bids or requests form a part of this specification to the extent specified herein.

MIL-R-9300	Resin Epoxy, Low-Pressure Laminating
ASTM-D-696	Coefficient of Linear Expansion of Plastics
ASTM-D-2702	Determination of the Infrared Absorption Characteristics of Rubber Chemicals
AMS-3894	Graphite Fiber Tape and Sheet

3.0 REQUIREMENTS

3.1 Fibers

3.1.1 Fiber Types. The classification types as noted in Section 1.2 shall be employed. When a specific product is needed, a commercial fiber meeting the requirements of type and class as noted in Sections 1.2.1, 1.2.2 will be specified by name on the purchase order.

3.1.2 Surface Treatment. All fibers shall have a active surface treatment or sizing which will be compatible with the resin system employed. The prepreg certification document shall contain the process identification number, as specified by the Fiber Manufacturer, for the sizing or surface treatment employed. If no such number is available, then a statement by the prepreger insuring the procuring activity that a compatible surface treatment has been used on the fiber is required.

3.1.3 Mechanical Properties. Nominal and minimum acceptable modulus, strength, and density properties of the fiber types are given in Table I. It will be the responsibility of the prepreg supplier to ascertain that the fiber properties fall within the prescribed limits. The prepreg delivery document shall contain the fiber property certification for the fiber lot used in the preparation of the prepreg.

3.1.4 Workmanship. The graphite material shall be suitable for production of a high quality finished product, and as such, shall not contain any evidence of foreign matter, fiber deterioration, discontinuity, loops, entrapped ends, fuzz balls, or excessive sizing which could cause adherence of adjacent strands and breaking during an unwinding process.

3.1.5 Handling. Normal handling of the graphite tow, yarn or tape shall not degrade the mechanical properties. Material will be stored on spools having a diameter of not less than three inches.

3.2 Resin

3.2.1 Quality. The resin system to be used for the prepreg material specified herein shall be of high quality and entirely suitable for impregnation of surface treated graphite yarns, tows, and tape.

3.2.2 Properties. The resin system employed shall be of a quality to meet the specified requirements of this document. It shall meet the general requirements of MIL-R-9300, in particular paragraphs 3.2, 3.3, 3.4, 3.5, 3.8, and 3.9.

3.2.3 Designation. The specific vendor resin system designation will be specified on the procurement document.

3.2.4 Formulation Change. A letter of specification compliance shall be required with each prepreg shipment. Such a document will guarantee that no resin formulation changes have occurred since the time of qualification.

3.3 Prepreg - Uncured

3.3.1 Prepreg forms. Graphite tows, yarns, woven fabrics and tapes, when impregnated with a resin system as described above, shall constitute a prepreg system. Several forms of prepreg systems are described as follows:

3.3.1.1 Prepreg Yarn. Single yarns or tows, resin preimpregnated, and partially staged and packaged in single, non-contacting layers on a 12 inch long by 3 inch diameter spool (approximate).

3.3.1.2 Prepreg Unidirectional Tape. Multiple single yarns or tows collimated into wide flat dry tapes of continuous parallel fibers. These are then resin preimpregnated, partially staged, and packaged in level wound roll form. Tape width may vary from 1/4 inch to 24 inches. Standard width is 3 inches. The package roll shall have a minimum radius of 3 inches.

3.3.1.3 Woven Fabric. Suitable graphite yarns and tows are cross woven to a specified pattern on mill equipment. The fabric is treated, resin preimpregnated and staged. Prepreg size shall be continuous in the warp direction and not less than 24 inches in the fill direction. The fabric shall be produced and packaged in accordance with the applicable purchase order.

3.3.1.4 Chopped Mat. Suitable graphite yarns or tows shall be chopped to a specified length, usually 1/2 to 1 inch, and immersed in a wide flat sheet of resin. The fiber orientation shall be random so as to generate isotropic properites in the plane of the sheet. After staging, the mat shall be packaged in accordance with the applicable purchase order.

3.3.2 Prepreg Properties

3.3.2.1 Physical Properties. The Grade A resin prepreg material shall meet the physical property requirements set forth in Table II. The tests shall be performed on prepreg material which is stored at 0°F for not less than 16 hours and returned to ambient temperature.

3.3.2.2 Prepreg Cosmetics

3.3.2.2.1 General Requirements. The prepreg materials should be well aligned, of constant thickness, and free of foreign materials, resin rich or resin starved areas, yarn or tow crossovers, knots, wrinkles, and an excessive number of splices and gaps. If, within a given roll of material, there are areas not conforming to this specification, they will be properly noted by flagging with a colored tag.

3.3.2.2.2 Alignment

(1) Tape: Alignment of the collimated tow or yarn within the impregnated tape shall not deviate more than .020 inches in any one linear foot. Areas not conforming to this criteria shall be flagged.

(2) Single yarn/tow: All fibers within the yarn or tow shall remain in close proximity to one another. No kinking, curling, or knotting of the fiber bundle will be permitted. Variations in wetted fiber bundle diameter greater than one half the mean diameter are cause for rejection. Non-conforming areas shall be flagged.

(3) Woven Fabric: The alignment of the warp and fill yarns of the fabric shall be perpendicular to each other and shall be parallel in the warp and fill direction of the impregnated fabric within a two inch span of the full cloth width exclusive of selvage, or 42 inch length, but not more than 1 inch in any 21 inches of cloth width or length. Areas not conforming to this criteria shall be flagged.

(4) Chopped Mat: A completely random orientation is required so as to generate isotropic properties in the plane of the mat.

3.3.2.2.3 Width

(1) Tape: Material shall be supplied in widths specified on the purchase document. Tape width tolerance shall be ±0.1 inch for nominal widths of 1 to 12 inches inclusive.

(2) Single yarn/tow: To be specified on the purchase document.

(3) Woven Fabric: The impregnated fabric width shall remain within a tolerance of plus or minus one inch of the specified purchase order width. The specified width shall be exclusive of the selvage areas of the impregnated material.

(4) Chopped Mat: Chopped mat supplied to this specification shall remain within plus or minus one-half inch of the dimensions described in the applicable purchase order.

3.3.2.2.4 Gaps

(1) Tape: Continuous gaps between adjacent tows or yanrs not exceeding 0.10 inch are acceptable provided that no more than three of these gaps occur simultaneously over any three inch width. Continuous gaps between adjacent tows or yarns shall not exceed .1 inches in width by six inches in length and shall not be more than eight feet accumulative total length for each hundred feet of length. Gaps in excess of this criteria shall be flagged as non-conforming areas and shall not be included in the net weight of the roll of material.

(2) Single Yarn/tow: No visually observable gaps are acceptable. Spools having more than ten gaps per 100 feet of prepreged yarn/tow are acceptable provided the 100 foot sections are flagged. These sections shall not be included in the net spool weight.

(3) Woven Fabric: Continuous gaps between parallel tows or yarns not exceeding 0.025 inch are acceptable in both warp and fill directions. Gaps up to 1/8 inch wide by 2 inches long between parallel fibers (warp or fill) are acceptable so long as no more than five such gaps appear in any foot square section of fabric. An entire fabric sheet (2 feet by 5 feet, or greater) shall be rejected if more than forty 1/8 inch wide gaps are present.

(4) Chopped Mat: An entire mat sheet (2 feet by 5 feet, or greater) shall be rejected if more than forty 3/16 inch diameter gaps (holes) are visible in the sheet.

3.3.2.2.5 Splices

(1) Tape: Splices of individual parallel yarns/tows are permitted so long as no two occur within 1/2 inch of each other. No splices shall be permitted across the width of the tape.

(2) Single yarn/tow: Splices in the prepreged yarn/tow roving are permitted providing the splice length is 1 to 2 inches, and no more than one splice occurs in any 100 foot section.

(3) Woven Fabric: Anomolies in the cosmetic appearance of the woven fabric which are a result of splices in the yarn controlled by the yarn specification or revisions thereof shall be identified by a colored marker in the selvage area of the woven fabric. The presence of these anomolies shall not be considered as non-conforming areas.

3.3.2.2.6 Flatness

(1) Tape: The prepreg tape shall adhere uniformly to the carrier material and shall not wave out of plane from the carrier. Areas not adhering to the carrier or exhibiting an out of plane wave greater than .02 inch will be flagged.

(2) Woven Fabric; Fabric sheets shall, when unrestrained, lay flat within ± 1/4 inch. A 1/2 inch border around the sheet will be exempt from this requirement.

(3) Fiber Mat: Same as (2), Woven Fabric.

3.3.2.2.7 Flash

(1) Tape: Resin flash shall not extend 1/16 inch beyond the edge of the tape.

(2) Single yarn/tow: Resin flash shall not extend 1/64 inch beyond the edge of the tow/yarn.

3.3.2.2.8 Material Uniformity. Prepreg areas shall be flagged for any of the following reasons:

(1) Tow/yarn crossovers and knots.

(2) Material wrinkles (marcelling) greater in amplitude than $\pm$ 1/64 inch and not covered by the alignment requirement.

(3) "Fuzzballs" which adhere to the prepreg tape or fabric and which cannot be removed with a pick or tweezers without damaging underlying fibers.

(4) Puckering due to excessive or uneven tension on the separator film.

(5) Appearance of foreign matter of any observable form on the prepreg, to include dirt particles, fingerprints, moisture, etc., and films such as oil, glazing, lacquer, etc.

(6) Incomplete splices, fish eyes, resin rich or resin starved areas, gaps, or buckles or other anomalies associated with material non-uniformity.

3.3.3 Prepreg Carrier

3.3.3.1 Tape Carrier. A thin paper, plastic, or equivalent carrier tape, at least as wide as the prepreg shall be used for backing material. It will be light colored so as to contrast to the black graphite prepreg and will be coated with a fully cured non-transferring release agent. The prepreg will adhere to the paper tape but be easily removable at ambient conditions by manufacturing personnel. Also, the prepreg-carrier combination will be easily cut with an ordinary paper cutting device.

3.3.3.2 Single yarn/tow Carrier. The same paper carrier described above in 3.3.3.1 will be used. The carrier here, however, will serve only to separate successive layers of single yarn/tow on the spool, as described in Section 3.3.1.2.

3.3.3.3 Woven Fabric Carrier. The same paper carrier used in 3.3.3.1 is acceptable here. No requirement exists, however, that the fabric stick to the carrier. The carrier will extend at least 1 inch beyond the specified purchase order width.

3.3.4 Prepreg Handling Characteristics

The prepreg material, when handled by experienced manufacturing personnel, will not tear, shred, fray, or become otherwise damaged. The material shall maintain tack and drape as tested by 4.10.3.5 and 4.10.3.6 for the duration of its working life.

3.3.5 Prepreg Storage

3.3.5.1 Shelf Life. The prepreg material shall meet the requirements of this specification when stored for 180 days at 0°F or 270 days at -65°F. Storage time commences on date of receipt.

3.3.5.2 Working Life. The prepreg material shall meet all requirements of this specification after exposure (either continuous or accumulative) from 65° to 85°F for 10 days while stored in a sealed, moisture proof plastic bag. If not bag sealed, the prepreg shall still meet all requirements of this specification after room exposure (85°F, 75 percent humidity maximum conditions) for 72 continuous or accumulative hours.

3.4 Prepreg - Cured Laminate

3.4.1 Test Laminate Fabrication

Cured laminate properties shall be determined from specimens prepared in accordance with Section 4.9.1.

3.4.2.1 Fiber-Resin-Void Content of cured laminates shall be measured as per 4.10.4.2 or an approved vendor process and shall conform to the limitations in Table III.

3.4.2.2 Laminate Thickness shall be measured as per 4.10.4.3 and shall conform to the limitations in Table III.

3.4.2.3 Composite Density shall be measured in accordance with Section 4.10.4.1.

3.4.2.4 Thermal Coefficient of Expansion in the longitudinal and transverse directions will be measured in accordance with ASTM D-696 (Coefficient of Linear Thermal Expansion of Plastic) or equivalent.

3.4.3 Mechanical Properties

3.4.3.1 Specimen Geometry. Tape, fabric, yarn, and chopped mat materials shall utilize flat geometries for acceptance and qualification tests. The vendor shall certify that the prepreg yarn/tow, if formed into wide tape could be laminated into unidirectional specimens having the properties of Table IV.

3.4.3.2 Thermal Requirements. Specimens shall be mechanically tested at room temperature and 350°F. The number of required tests at temperature is provided in Table IV. Thermal expansion coefficients will also be measured at room temperature and 350°F.

3.4.3.3 Modulus/Strength Requirements

3.4.3.3.1 Tape. The mechanical properties of unidirectional composites fabricated from Grade A resin prepreg tapes shall meet the requirements of Table IV. All strength and modulus test data shall be normalized for 63 percent fiber volume as described in Section 3.4.3.4. Laminates under test must meet the physical property limits set forth in Table III.

3.4.3.3.2 Yarns/Tows. The tensile modulus and strength of laminated composites fabricated from yarns/tows into rings shall conform to the appropriate fiber value of Table IV. Values shall be normalized as necessary.

3.4.3.3.3 Fabric. The following mechanical properties for woven fabric shall be specified on the purchase document:

(1) Warp and fill tensile strengths.

(2) Warp and fill tensile moduli.

(3) Warp and fill flexural strengths.

(4) Warp and fill flexural moduli.

(5) Warp and fill short beam (interlaminar) shear.

(6) Allowable coefficients of variation.

The above properties (both minimum and average values) shall be specified at room temperature and 350°F. The appropriate tests shall be conducted to insure conformance with these specified properties.

3.4.3.3.4 Chopped Mat. The following isotropic mechanical properties (both minimum and average values) shall be specified on the purchase document:

(1) Tensile strength
(2) Tensile modulus
(3) Flexure strength
(4) Flexure modulus
(5) Allowable coefficients of variation

The above properties shall be specified at room temperature and 350°F. The appropriate tests shall be conducted to insure conformance with these specified properties.

3.5 Normalized Properties

All longitudinal tensile and longitudinal flexure mechanical property requirements shown in Table IV are based on a 63 percent fiber volume. Normalize mechanical data by using the correction factor (AFV/63) as follows:

$$\sigma_c = \sigma_{test} \cdot \left(\frac{63}{AFV}\right)$$

$$E_c = E_{test} \cdot \left(\frac{63}{AFV}\right)$$

where AFV is the actual fiber volume, percent, as determined by 4.10.4.2, σ_{test} and E_{test} are the test data as determined by 4.10.4.5, 6, 7, and σ_c and E_c are the corrected values.

3.6 Statistical Reduction of Data

The coefficient of variation for all composite mechanical test data shall be computed as follows:

Mean value $$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N}$$

Standard deviation $$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (\bar{X} - X_i)^2}{N - 1}}$$

Coefficient of variation $$V = \frac{\sigma}{\bar{X}} \times 100$$

where X_i are the test data and N is the test population.

The maximum allowable coefficients of variation are given in Table IV. Material lots not meeting this requirement shall be rejected. A retest for any and all mechanical properties failing to meet this variational requirement shall be permitted, so long as the minimum and average values of Table IV have been met. This paragraph takes specific exception to Section 4.7.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Qualification Tests

Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the procuring activity. The procuring activity reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements. Table V (a) is a list of the mechanical and physical tests required for qualification of a material system. The vendor shall be required to perform all tests unless other wise specified. Table VI and Table VII show the number and type of specimen required.

4.2 Acceptance Tests

Acceptance tests are those tests required for each shipment or lot of material to insure the quality of the product. Acceptance tests shall consist of those listed in Table V (b).

The specific number of tests for the various properties and the required test temperatures are shown in Table VI. The minimum number of panels required to obtain the correct number of specimens are listed in Table VII.

4.3 Test Reports

Complete test inspection records shall be maintained by the prepreg supplier. Test reports as required by this specification shall be prepared and delivered to the procuring activity at the time of material delivery.

4.4 Sampling Units

4.4.1 Lot. A lot is the prepreg material produced in one manufacturing run under relative uniform conditions. Lot numbers will be specified by the prepreg supplier.

4.4.2 Unit. One roll of continuous tape, yarn, or fabric or a maximum of 10 pounds of sheet material.

4.5 Qualification/Acceptance

4.5.1 Qualified Vendor. A vendor will be qualified for a material system when all requirements of this specification are met and vendor test data is supplied to and verified by the procuring activity. A qualification test report detailing the test results as required by Table V shall be delivered to the procuring activity.

4.5.2 Acceptance. Qualified vendors shall be required to complete all acceptance test requirements listed in Table V. An acceptance test report shall be delivered to the purchasing agency, including unimpregnated material data described in Tables I and V.

4.5.3 Certification. The prepreg vendor shall certify that each delivery meets all requirements of this specification.

4.5.4 Formulation and Process Change. A vendor cannot change the materials or fabrication process of a qualified product without prior notification to and approval of the procuring activity. Such changes may require requalification.

4.5.5 Witness. The procuring activity reserves the right to witness any and all testing conducted by or for the prepreg vendor.

4.6 Cause for Rejection

4.6.1 Prepreg. Defective areas of preimpregnated tapes, yarns/tows, fabrics, and mats not conforming to the requirements of 3.3.2.2 (cosmetics) shall be flagged as non-conforming areas and shall not be included in the net weight of a given material type. Prepreg units shall also be rejected for nonconformance as specified in 3.3.4 (handling). Remaining portions of an acceptable lot shall be rejectable for nonconformance to 3.3.5 (storage life).

4.6.2 Cured Laminates. The entire material lot shall be rejected for nonconformance with 3.4.3.3 (modulus and strength requirements).

4.7 Retest

Should a material lot fail to meet one or two acceptance or qualification requirements, a retest of the failed properties is permitted. The material lot shall be acceptable if the requirements are met on the retest. A second retest is not permitted.

4.8 Recertification

The procuring activity reserves the right to require recertification of any vendor.

4.9 Fabrication of Test Specimens

4.9.1 Flat Panels. The actual cure cycle and laminate fabrication procedure will be selected by the prepreg vendor. After flat panels have been fabricated, actual test specimens will be prepared in accordance with AMS 3894, except as noted in Section 4.10.4. Tensile, flexure and short beam shear specimens shall be cut from the completed test panels. Also, the panels should be made sufficiently large so that the specimens needed for thermal expansion and fiber-resin-void determination may be obtained.

An optional layup procedure is shown in Figure 1. For Grade A resins, the pressure-temperature cure cycle should consist of an initial heat up to 250°F (6° - 10°F/min) under vacuum bag pressure (14 psi), application of 50-100 psi autoclave pressure and optional venting of vacuum bag, heat up to 350°F, dwell for 1-2 hours, cool down under pressure, and final release of pressure. Any significant deviations from this process shall be noted. The prepreg vendor shall specify the cure cycle on the test report.

NOTE: For Grade A resins only, cure pressures in excess of 125 psi or cure temperatures in excess of 400°F are unacceptable.

4.10 Test Procedures

4.10.1 Fiber Tests. Any tests required by the prepreg vendor on the fiber shall be specified by the prepreg vendor. Results of such tests will be reported to the procuring activity.

4.10.2 Resin Tests. The extent and type of tests performed on each batch of resin formulation prior to and during the impregnation process shall be at the discretion of the prepreg vendor. Results of such tests will be reported to the procuring activity, provided that the disclosure of such test results will not, in the opinion of the prepreger, compromise a proprietary formulation. A statement on the prepreg certification as to the type resin employed is required.

4.10.3 Uncured Prepreg Tests

4.10.3.1 Nonfiber content. Nonfiber content, percent by weight of the uncured prepreg, shall be determined by either an approved vendor substitute process or per AMS 3894 with the following differences:

(1) Demethylformamide or methylene chloride shall be employed as the solvent.

(2) Use a minimum of 100 ml fresh solvent for each washing.

(3) In place of solvent boiling soak, the uncured prepreg samples can be solvent extracted using a Soxhlet Extraction apparatus, recycling the solvent at least 4 to 10 times every hour for a minimum of 6 hours.

(4) All samples are to be weighed within 20 seconds after removal from dissicator.

4.10.3.2 Resin Flow. Resin Flow, percent by weight of the uncured prepreg, shall be determined by either an approved vendor substitute process or per AMS 3894 with the following differences:

(1) Platen to be preheated to 325° $\pm$ 5°F.

(2) Apply 50 $\pm$ 3 psi.

(3) Bleeder cloth shall be 120 or 181 style fiberglass, or equivalent.

(4) Release cloth may be EMFAB TX1040 or equivalent.

4.10.3.3 Volatiles. Volatile content, percent by weight of the uncured prepreg, shall be determined by either an approved vendor substitute process or per AMS 3894 with the following differences:

(1) Tests to be conducted at 325° $\pm$ 5°F.

(2) Heat samples for 15 to 16 minutes.

(3) Volatile tests at temperatures and times recommended by the vendor, if different from this specification, will also be conducted and reported.

(4) Specimen shall be suspended by alligator clip or equivalent.

4.10.3.4 Gelation. Resin gel time shall be determined by either an approved vendor substitute process or per AMS 3894 with the following differences:

(1) Repeat gel test at 3 different temperatures, 180°, 250°, 350F for qualification tests (test at 350°F only for acceptance tests).

(2) Plot on semilog paper, gel time on logarithmic axis.

(3) Reaction rate, C, shall be determined as follows:

$$C = \frac{\log \theta_1 - \log \theta_2}{[\log e]\,[T_1 - T_2]}$$

where θ_1 = gel time at lower temperature T_1

θ_2 = gel time at higher temperature T_2

T_1 = lower temperature taken from straight line plot

T_2 = higher temperature taken from straight line plot

$\log e = 0.434$

NOTE: The material lot shall be rejected if the gel time at 350°F exceeds (To be determined) minutes.

4.10.3.5 Tack. Prepreg tack shall be determined by either an approved vendo substitute process or per AMS 3894 with the following differences:

(1) Clean smooth glass surface may also be used as a test panel.

(2) When touched lightly with clean hands, the resin will not transfer from the prepreg to the fingers at 70 to 75°F.

4.10.3.6 Drape. Prepreg drape shall be reported as "pass" or "fail."

4.10.3.6.1 For unidirectional staged prepreg tape, cut three 2 inch long by 3 inch wide samples. Each specimen will be bent 90° over a 1/8 inch radius clean metal surface at room temperature (70°-77°F). The bend will be made parallel to the fiber orientation and the sample will be pressed against the metal surface with light contact pressure. To pass the drapability test, the specimens shall adhere to the metal surface for 10 minutes without springback, and no fiber damage shall be visible under 10x magnification. All three tests must pass to meet the drapability requirement.

4.10.3.6.2 For fabric prepreg, six 3 inch square specimens will be used. The drape test will be conducted as in 4.10.3.6.1 for both warp and fill directions. All six tests must pass to meet drapability requirements.

4.10.3.6.3 An approved vendor substitute process may be used for the drape test.

4.10.3.6.4 Material exposed to ambient conditions for more than 24 hours (unsealed) shall not be subjected to the drape test.

4.10.3.7 Staging. Prepreg material, when delivered to the Purchaser, shall be staged. The degree of staging, as well as the required test procedures to determine same, may be specified on the purchase document.

4.10.3.8 Infrared Spectrograph. An infrared spectrograph of the staged resin shall be supplied at the time of certification. The procedure employed to extract the staged resin from the prepreg, including solvents employed, method of solvent removal and type of infrared cells employed shall be reported. Procedures outlined in ASTM D2702 shall be followed.

4.10.4 Cured Prepreg (Laminate) Tests

4.10.4.1 Density. The density of a test laminate shall be determined in accordance with ASTM D792.

4.10.4.2 Fiber/Resin/Void Content. Using specimens from the same test laminates prepared for mechanical testing, the laminate fiber/resin/void content shall be determine using either an approved vendor substitute method or a nitric acid digestion technique outlined in AMS 3894 with the following differences;

(1) Stabilize the temperature of the nitric acid using a boiling water bath at 212°F.

(2) The sample to be tested will be in one piece of at least 3 grams.

(3) Digest the sample in the hot nitric acid for 90 - 100 minutes, stirring continuously with a magnetic stirrer or once every 10 minutes with a glass rod.

(4) Cool the sample 30 minutes.

(5) Filter with an all glass filter apparatus, using vacuum assist, with Millipore Corporation's (Bedford, Massachusetts) LCWP04700 Filters, or equivalent.

(6) Rinse the fibers in the filter as follows:

Twice with 100 ml each HNO_3

Twice with 100 ml each distilled water

Twice with 100 ml each acetone

When rinsing, stop vacuum, add the liquid, stir, then apply vacuum. Remove the liquid from the Buchner funnel when changing type of rinse.

(7) Dry the carbon fibers in a vacuum oven set at 212° ± 5°F @ 29 inches mercury vacuum for one hour minimum.

(8) Cool in desiccator.

(9) Weigh within 20 seconds of removal from desiccator.

Computations are as follows:

% Fiber (weight) $\left(\frac{W_f}{W_L}\right) \times 100$

% Resin (weight) $\left(\frac{W_L - W_f}{W_L}\right) \times 100$

% Fiber (volume) = FV = $\left(\frac{W_f}{W_L}\right)\left(\frac{\rho_L}{\rho_f}\right) \times 100$

% Resin (volume) = RV = $\left(\frac{W_R}{W_L}\right)\left(\frac{\rho_L}{\rho_R}\right) \times 100$

% Void (volume) = VV = 100 − FV − RV

where

W_L = weight (grams) of laminate before digestion

W_f = weight (grams) of fiber after digestion

ρ_L = density (g/cc) of laminate before digestion

ρ_f = density (g/cc) of fiber as determined by prepreg vendor in 4.10.1.

ρ_R = density (g/cc) of resin as determined by prepreg vendor in 4.10.2.

Three separate acid digestion tests will be conducted on the test laminate. Results of all three tests will be reported.

4.10.4.3 Laminate Thickness. The laminate used to determine ply thickness shall be of the $[0/90/0/90]_{sym}$ type. Laminate thickness shall be measured using a suitable micrometer having ball contact heads. A minimum of 10 evenly spaced readings shall be made, all being at least 1/2 inch from any edge. Laminate thickness shall be the average of 10 readings. Average ply thickness will be reported as

$$t/\text{ply} = \frac{\text{thickness of laminate}}{\text{total number of plies}}$$

4.10.4.4 Tensile Strength, Modulus

4.10.4.4.1 Flat Specimens. Longitudinal and transverse tensile specimens shall be tested in tension and modulus and strength data shall be determined in accordance with AMS-3894 with the following noted exceptions.

(1) Crosshead speed shall be 0.050 inches/minutes.

(2) Five fabric specimens in the fill direction shall be tested at room temperature and five fabric specimens in the fill direction shall be tested at 350° ± 5°.

(3) Five fabric specimens in the warp direction shall be tested at room temperature and five fabric specimens in the warp direction shall be tested at 350° ± 5°.

(4) Five longitudinal tape specimens shall be tested at room temperature and five shall be tested at 350° ± 5°. Five transverse tape specimens shall be tested at room temperature.

(5) For measuring fabric specimen dimensions, a micrometer with one flat anvil and 0.200 inch diameter ball shall be used. A ball micrometer shall be used for tape specimens.

(6) Procedural testing shall be in accordance with specification AMS-3894 except that specimen length shall be 9.0 inches, and width shall be .50 inches.

(7) Calculation of modulus of elasticity for room temperature specimens shall require the use of an extensometer or strain gages and elevated temperature testing shall employ the use of strain gages.

(8) For 350° ± 5°F. testing: The thermocouple shall be positioned within one-half inch of each specimen to be tested and testing shall be conducted after 10 ± 1 minutes exposure to the specified temperature requirement.

(9) Longitudinal tensile strength and modulus values shall be normalized to 63 percent fiber volume.

(10) Five tests are required for the modulus/strength value. Report the average and the individual test data. Compute and report normalized values and coefficient of variation in accordance with Sections 3.5, 3.6.

4.10.4.5 Flexure Strength/Modulus. Longitudinal and transverse specimens shall be tested in flexure and flexural strength and modulus data shall be determined in accordance with AMS-3894 with the following exceptions.

(1) Crosshead speed shall be 0.050 inches/minute.

(2) Five fabric specimens in the fill direction shall be tested at room temperature and five fabric specimens in the fill direction shall be tested at 350° ± 5°F.

(3) Five longitudinal tape specimens shall be tested at room temperature and five at 350° ± 5°F. Five transverse tape specimens shall be tested at room temperature and five at 350°F ± 5°F.

(4) Procedural testing shall be in accordance with AMS-3894. Either three point or four point loading may be used. The method shall be specified on the test report.

(5) Longitudinal strength and modulus values shall be normalized to 63 percent fiber volume.

(6) The thermocouple shall be positioned within 1/2 inch of each specimen to be tested at 350° ± 5°F.

(7) An optional method of computing the flexural modulus will utilize the crosshead motion corresponding to the 1/4 span deflection, in which case

$$E_f = \frac{(L - a)\ (2a^2 - La - L^2)}{4bt^3} \quad \left(\frac{\Delta P}{\Delta y}\right)$$

where

L = span, in.

a = 1/2 span, in.

t = thickness, in.

b = width, in.

ΔP = load increment measured by load cell, lbs.

Δy = deflection increment at 1/4 span, in.

(8) Compute and report the actual test values, the normalized values, and the coefficients of variation as required in Sections 3.5. and 3.6.

4.10.4.6 Short Beam Shear. Short beam (interlaminar shear) will be determined in accordance with AMS-3894 with the following noted exceptions.

(1) Crosshead speed shall be 0.050 inches/minute.

(2) Five fabric specimens shall be tested in the warp direction at room temperature and five fabric specimens shall be tested in the warp direction at 350° ± 5°F.

(3) Five tape specimens shall be tested at room temperature and five tape specimens shall be tested at 350° ± 5°F.

(4) Procedural testing shall be in accordance wtih specification AMS 3894.

(5) The thermocouple shall be positioned within 1/2 inch of each specimen to be tested at 350° ± 5°F.

(6) The specimen length (fiber direction) shall be .600 ± .005 inch.

(7) Nominal specimen thickness is .080 inch, and will not vary more than .002 inch over its entire length or width.

(8) Flexure failures may occur when span to thickness ratio is not small enough to induce a shear stress failure. In such cases, lower span to thickness ratios will be required and may best be obtained by increased thickness.

(9) Crosshead must be stopped immediately after load begins to drop off so that a shear failure can be observed. Continued motion will result in flexural failure, masking the true result. Typical shear and flexure failures are shown in Figure 2. Flexure failures must be reported as such.

(10) Compute and report the actual test values, and the coefficients of variation as required in Sections 3.5 and 3.6.

4.11 Warranty Period. The warranty period shall be the same as the material shelf life. Should a material lot fail to meet the acceptance test criteria at a time subsequent to initial acceptance testing but prior to the shelf life expiration date (subject to 3.3.5), the remainder of the lot may be returned to the vendor for remuneration.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging and Shipping

5.1.1 Tape. The prepreg material, together with its carrier tape, will be wound under tension on to rolls or spools having a minimum inner diameter of 8 inches. The back surface of the carrier or separator paper will be clean and contain no materials which may contaminate the prepreg. Protective flanges will be incorporated on the rolls. Unless specified on the purchase document, no roll shall contain less than 20 or more than 10 pounds of acceptable prepreg. Each roll will be individually sealed in a clear, moisture proof, plastic bag, and labeled as per 5.2.1. Units packed in the preceeding manner will be shipped in insulated containers capable of using solid CO_2 to keep material temperatures below 0°F during transit. Prepreg will be removed from shipping containers and immediately placed in 0°F (or below) storage.

5.1.2 Single yarn/tow. The prepreg yarn/tow will be wound under tension on to spools having a minimum outer diameter of 3 inches and length of approximately 10 inches. The winding will be in the form of continuous non-contacting layers of adjacent hoop windings of fiber bundles, each layer being separated from the previous one by a sheet of separator paper placed circumferentially on the spool. The outermost layer of prepreg will be covered by a separator sheet. Unless specified on the purchase document, no roll will contain more than 3 pounds of prepreg. Each roll will be individually sealed in a clear moisture proof plastic bag, and labeled as per 5.2.1. Units so packed will be shipped in accordance with Section 5.1.1.

5.1.3 Woven Fabric, Chopped Mat. Fabric and chopped mat will be packaged in accordance with the applicable purchase order. Unless specified on the purchase document, sheet size will be nominally 2 feet wide (fill) by 5 to 6 feet long (warp). Stacked sheets will be separated from one another with clean separator material as specified in 3.3.3.3 and the entire stack will be bound top and bottom with thick, protective cardboard or equivalent. The packages will be taped and sealed in a moisture proof, clear plastic bag and labeled in accordance with Section 5.2. Shipment will be as described in 5.1.1.

5.2 Marking

5.2.1 Bag and Core. The following information shall be attached to the core of each roll or spool, and for fabric/mat to the cardboard surface containing the prepreg, and shall be visible through the clear, moisture proof, plastic sealing bag:

(1) Manufacturers name, symbol

(2) Material type; resin, resin/catalyst lot number, fiber, and prepreg designation.

(3) Lot and roll number

(4) Material Quantity: Linear feet and weight, if tape
Weight and approximate footage, if yarn
Weight and approximate square footage, if fabric or mat

(5) Storage life expiration date at 0°F

(6) Label stating "CAUTION: STORE AT OR BELOW 0°F." or equivalent

5.2.2 Shipping Package. Each shipping container shall have attached a clearly visible document detailing:

(1) Manufacturers name, symbol

(2) Material Designation

(3) Material Quantity

(4) Date of Manufacture

(5) The Procuring Activity Purchase Order number

(6) Warranty expiration date of material when stored at 0°F

5.2.3 Warning Sign. Each shipping container shall have visible a colored sign stating "CAUTION: STORE AND SHIP AT OR BELOW 0°F." or equivalent.

6.0 NOTES

6.1 Purchase Order. The following information, when applicable, shall appear on the purchase order:

Fiber designation	3.1.1
Resin designation	3.2.3
Tape Width	3.3.2.2.3
Yarn Width	3.3.2.2.3
Fabric, Mat Width	3.3.2.2.3
Fabric Mechanical Properties	3.4.3.3.3
Mat Mechanical Properties	3.4.3.3.4
Prepreg Staging	4.10.3.7
Laminate Physical Properties	Table III
Quantity	

6.2 Prepreg Documentation. The following information as applicable, shall appear on documentation either accompanying the prepreg shipment or mailed under separate cover:

Fiber Property Certification	3.1.3
Fiber Surface Treatment	3.1.2
Fiber Test Results	4.10.1
Resin Certification	4.10.2
Yarn Property Certification	3.4.3.1
Test Report	4.3
Qualification Report	4.5.1
Acceptance Report	4.5.2
Statement of Certification	4.5.3
Cure Cycle	4.9.1
Infrared Spectrograph	4.10.3.8
Packing Data	5.2.1, 5.2.2

FIBER TYPE	ELASTIC MODULUS $E_t \sim 10^6$ psi		TENSILE STRENGTH σ_t (ultimate) $\sim 10^3$ psi		DENSITY $\rho \sim$ g/cc	
	Nominal	Minimum*	Nominal	Minimum*	Nominal	Minimum*
I	57	50	325	250	1.70	1.65
II	36	28	375	350	1.79	1.72
III	32	25	350	300	1.76	1.70
IV	74	70	250	220	1.96	1.91
V	74	70	250	220	1.96	1.91

* Minimum Individual Value

TABLE I. FIBER PROPERTIES

PHYSICAL PROPERTY	REQUIREMENT				TEST METHOD
	PREPREG FORM				Referenced Paragraph
	Yarn	Tape	Fabric	Mat	
Non Fiber Solids (% by weight)	40 ± 3	40 ± 3	40 ± 3	50 ± 5	4.10.3.1
Resin Percent Flow (% by weight)	20 ± 3	20 ± 5	20 ± 4	25 ± 5	4.10.3.2
Volatile Content (% by weight)	2.0 MAX	2.0 MAX	2.0 MAX	2.0 MAX	4.10.3.3
Tack	Shall pass test as per				4.10.3.5
Drape	Shall pass test as per				4.10.3.6
Gelation	Shall be reported as per				4.10.3.4
Infrared Spectrograph	Shall be reported as per				4.10.3.8

TABLE II. Prepreg Physical Requirements
Grade A (epoxy) Resin

Prepreg Type	Property		Fiber Type			
			III	II	I	IV, V
Tape	t/ply	in.	.005-.006	.005-.006	.006-.007	.0045-.0050
	Fiber content	v/o	60-68	60-68	60-68	*
	Void content, max.	v/o	1.5	1.5	1.5	1.5
	Density	g/cc	1.57 $\pm$.05	1.58 $\pm$.05	1.63 $\pm$.08	1.63 $\pm$.05
Yarn	t/ply	in.	.005-.006	.005-.006	.006-.007	*
	Fiber content	v/o	60-68	60-68	60-68	*
	Void content, max.	v/o	1.5	1.5	1.5	1.5
	Density	g/cc	1.57 $\pm$.05	1.58 $\pm$.05	1.63 $\pm$.08	1.65 $\pm$.05
Fabric	t/ply	in.	*	*	*	*
	Fiber content	v/o	60-68	60-68	60-68	*
	Void content, max.	v/o	2.0	2.0	2.0	2.0
	Density	g/cc	1.58 $\pm$.05	1.58 $\pm$.05	1.63 $\pm$.08	1.65 $\pm$.05
Chopped Mat	t/ply	in.	*	*	*	*
	Fiber content	v/o	60-68	60-68	60-68	60-68
	Void content, max.	v/o	2.0	2.0	2.0	2.0
	Density	g/cc	1.56 $\pm$.05	1.57 $\pm$.05	1.63 .08	1.65 $\pm$.05

* To be specified on Purchase Document

TABLE III. Physical Properties Limits of Cured Prepregs.

Grade A (epoxy) Resin

Property	Temp. °F	Type III Min. Ave. Value*	Type II Min. Ave. Value	Type I Min. Ave. Value	Type IV, V Min. Ave. Value	Max. Coef. of Variation, %
Strength - Tensile						
Longitudinal	RT*	190	190	100	80	7.5(1)
(10^3 psi)	350*	175	175	90	80	7.5(2)
Transverse	RT	4.5	4.[illegible]	4.0	4.5	10
	350	2.5	2.[illegible]	3.5	4.5	15
Strength - Flexural						
Longitudinal	RT	220	220	100	95	7.5
(10^3 psi)	350	170	170	95	95	10
Transverse	RT	7.4	7.4	6.0	5.0	10
	350	5.1	5.1	4.0	3.0	15
Modulus - Tensile						
Longitudinal	RT	18.0	19.0	28.0	37.0	7.5
(10^6 psi)	350	17.5	18.0	27.0	36.0	7.5
Transverse	RT	1.0	1.0	1.0	.5	7.5
	350	.5	.5	.5	.3	7.5
Modulus - Flexural						
Longitudinal	RT	17.5	17.5	26.0	34.0	7.5
(10^6 psi)	350	16.5	16.5	25.0	33.0	10
Transverse	RT	1.0	1.0	1.0	.6	10
	350	.6	.6	.9	.5	15
Interlaminar Shear (Short Beam Shear)						
(10^3 psi)	RT	14.0	9.0	7.0	6.0	10
	350	7.5	6.0	4.0	4.0	15

(1) Applicable to Types I, II and III. 10 for Type IV and V.
(2) Applicable to Types I, II and III. 15 for Type IV and V.

* RT - Test conducted at Room Temperature
* 350 - Test conducted at 350°F after a minimum 10 minute soak at 350°F.
* Min. Ave. Value - Minimum average value of 5 specimen tests.

TABLE IV. Unidirectional Mechanical Properties of Flat Laminates Grade A (epoxy) Resin

Test	Requirement	Test Para.	Test Frequency	
			Tape, Yarn	Fabric, Mat
Cosmetics	3.3.2.2	3.3.2.2	Unit	Unit
Non Fiber Content	3.3.2.1	4.10.3.1	Unit	Lot
Resin Flow	3.3.2.1	4.10.3.2	Unit	Lot
Volatile Content	3.3.2.1	4.10.3.3	Unit	Lot
Gelation	3.3.2.1.	4.10.3.4	Unit	Lot
Tack	3.3.2.1	4.10.3.5	Unit	Lot
Drape	3.3.2.1	4.10.3.6	Unit	Lot
Infrared	3.3.2.1	4.10.3.8	Unit	Lot
Density	3.4.2.3	4.10.4.1	Laminate	Laminate
Fiber/Resin/Void	3.4.2.1	4.10.4.2	Laminate	Laminate
Thickness	3.4.2.2	4.10.4.3	Laminate	Laminate
0° Tension RT	3.4.3.3	4.10.4.5	Lot	Lot
350	3.4.3.3	4.10.4.5	Lot	Lot
90° Tension RT	3.4.3.3	4.10.4.5	Lot	Lot
350	3.4.3.3	4.10.4.5	Lot	Lot
0° Flex RT	3.4.3.3	4.10.4.6	Lot	Lot
350	3.4.3.3	4.10.4.6	Lot	Lot
90° Flex RT	3.4.3.3	4.10.4.6	Lot	Lot
350	3.4.3.3	4.10.4.6	Lot	Lot
0° SBS RT	3.4.3.3	4.10.4.7	Lot	Lot
350	3.4.3.3	4.10.4.7	Lot	Lot
90° SBS RT	3.4.3.3	4.10.4.7	N/A	Lot Fabric
350	3.4.3.3	4.10.4.7	N/A	Lot Only
Therm. Expan RT	3.4.2.6	3.4.2.6	Lot	Lot
0°, 90° dir. 350°	3.4.2.6	3.4.2.6	Lot	Lot
Fiber	Certification of Fiber properties required with Qualification tests in accordance with Para. 3.1.1 and 4.5.3			
Resin	Certification of Resin properties/tests required with Qualification tests in accordance with Para. 3.2 and 4.5.3			

* Test to be conducted by the procuring activity

TABLE V(a). Qualification Tests

Test	Requirement	Test Data	Test Frequency	
			Tape, Yarn	Fabric, Mat
Cosmetics	3.3.2.2	3.3.2.2	Unit	Unit
Non Fiber Content	3.3.2.1	4.10.3.1	Unit	Lot
Resin Flow	3.3.2.1.	4.10.3.2	Unit	Lot
Volatile Content	3.3.2.1	4.10.3.3	Unit	Lot
Gelation	3.3.2.1	4.10.3.4	Lot	Lot
Tack	3.3.2.1	4.10.3.5	Lot	Lot
Drape	3.3.2.1	4.10.3.6	Lot	Lot
Infrared	3.3.2.1	4.10.3.8	Lot	Lot
Density	3.4.2.3	4.10.4.1	Laminate	Laminate
Fiber/Resin/Void	3.4.2.1	4.10.4.2	Laminate	Laminate
Thickness	3.4.2.2	4.10.4.3	Laminate	Laminate
0° Flex RT	3.4.3.3		Lot	Lot
350	3.4.3.3		Lot	Lot
0° SBS RT	3.4.3.3		Lot	Lot
350	3.4.3.3		Lot	Lot
90° SBS RT	3.4.3.3		N/A	Lot Fabric
350	3.4.3.3		N/A	Lot Only
Fiber	Certification of fiber properties required with Acceptance tests in accordance with Para. 3.2 and 4.5.3			
Resin	Certification of Resin properties/tests required with Acceptance tests in accordance with Para. 3.2 and 4.5.3			

TABLE V.(b) Acceptance Tests

Material Type	Specimen Geometry	PROPERTY DETERMINED	No. of Specimens Required Per Material Lot	
			RT	350
Tape	Flat	0°Tensile σ,E,ε 90° Tensile σ,E,ε 0° Flex σ,E 90° Flex σ,E 0° SBS σ	5 5 5 5 5	5 5 5 5 5
Fabric	Flat	0°(Warp) Tensile σ,E,ε 90°(Fill) Tensile σ,E,ε 0°(Warp) Flex σ,E 90°(Fill) Flex σ,E 0°(Warp) SBS σ 90°(Warp) SBS σ	5 5 5 5 5 5	5 5 5 5 5 5
Chopped Mat	Flat	0°(X dir.) Tensile σ,E,ε 90°(Y dir.) Tensile σ,E ε 0°(X dir.) Flex σ,E 90°(Y dir.) Flex σ E 0°(X dir.) SBS σ	5 5 5 5 5	5 5 5 5 5
Yarn, Tow	Flat	Certify to unidirectional mechanical properties as per Table IV		

σ Ultimate stress, psi
ε Computed Ultimate Strain, μ in/in
E Elastic Modulus, psi
0° Fiber direction
90° Cross Fiber Direction

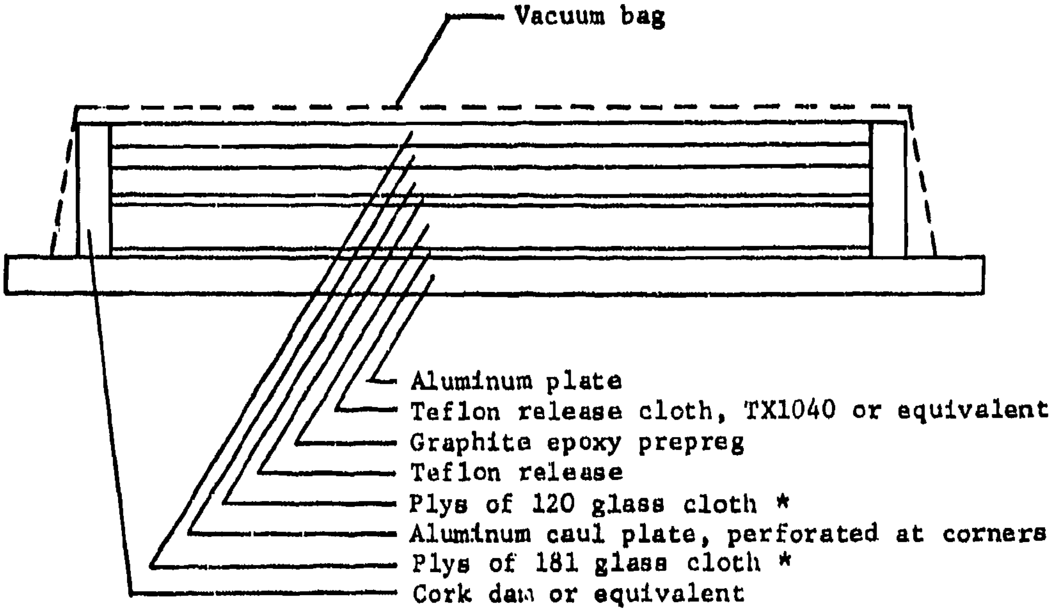
TABLE VI. Mechanical Test Specimen Requirements

Material Type	Mechanical Tests	Approx. Panel Size	No. of Req'd. Panels for Qual.	No. of Req'd. Panels for Accp.
Tape	0°, 90° Flex, @ RT, 350 0° SBS, @ RT, 350 0° Tens, @ RT, 350 90° Tens, @ RT, 350	8" X 16" X .08" 10" X 7" X .03" 10" X 12" X .08"	1 1 1	1
Fabric, Mat	0°, 90° Flex, @ RT, 350 0°, 90° SBS, @ RT, 350 0° Tens, @ RT, 350 90° Tens, @ RT, 350	8" X 16" X .08" 10" X 20" X .03"	1 1	1
Yarn, Tow	*		*	*

* To be determined

TABLE VII. Test Panel Fabrication for Mechanical Qualification - Acceptance Tests

(For Information Only)



* No. of plys of bleeder cloth dependent on No. of graphite plys; to be specified by vendor

NOTE: The layup procedure and cure cycle shall be specified by the prepreg vendor.

Figure 1. Layup for Prepregs (Optional)

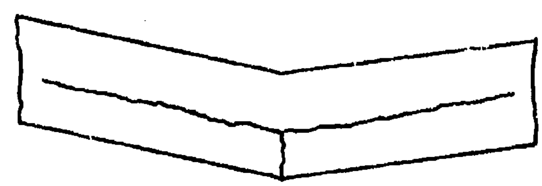


Figure 2A. Typical Interlaminar Shear

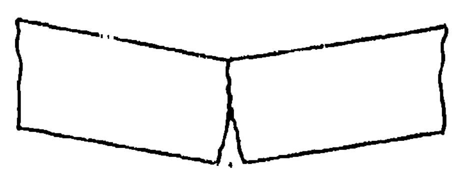


Figure 2B. Typical Flexural Failure

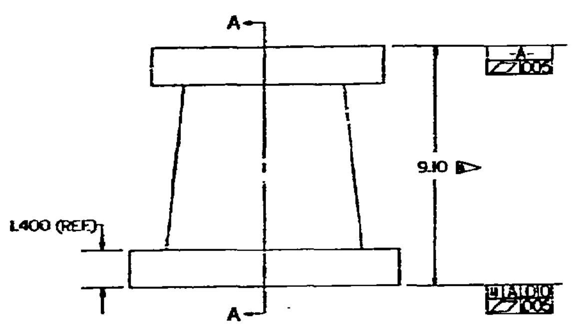
APPENDIX B

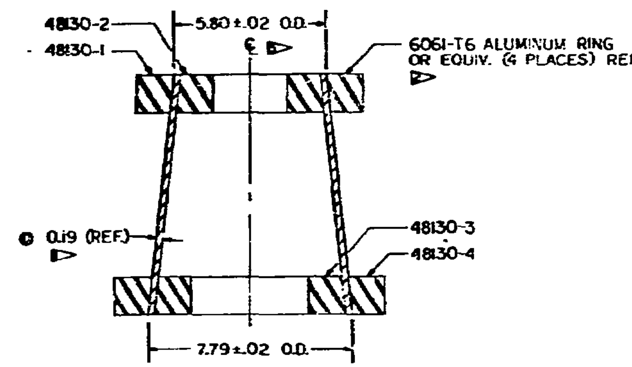
GY70/EPOXY CONICAL SHELL AND
SUPPORT RINGS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	C	REPLACES REVISION B WITH CHANGE.	6/7/75	
B5		LENGTH WAS 8.30, NOW 9.10		
C3		O.D. WAS 5.89; NOW 5.80±.02		
B5		O.D. WAS 7.71; NOW 7.79±.02		
D8		ADD NOTE 4		
C8		ADD NOTE 5		
B4	D	SHELL WALL WAS 0.25, NOW 0.19	10/24/75	

NOTES:

1. GY70/FIBERITE 934 PLY LAMINA LAYUP: $[0_2/45/90/-45/90/45/0_3/-45/0_3/45/0_2/-45/0]_S$
2. ALUMINUM RINGS SHALL BE FLUSH WITH ENDS OF SHELL.
3. CLEAN ALUM. RINGS PER PROCEDURE IN MIL-A-9067C, PARA. 6.1.1, OR EQUIV. AND BOND WITHIN 8 HOURS. SOLVENT WIPE GY70 SHELL BONDING SURFACES WITH PETROLEUM ETHER OR EQUIV., DRY, HAND SAND LIGHTLY, AND REMOVE DUST WITH DRY NITROGEN. BOND ALUM. RINGS TO GY70 SHELL WITH EA 9309 (HYSOL DIV.-THE DEXTER CORP) PER VENDOR'S RECOMMENDED MIX RATIO. MAINTAIN BOND LINE THICKNESS OF 0.004 IN. TO 0.125 IN. CURE FOR 72 HRS. AT 75°F±5°F OR FOR 6 HRS. AT 75°F±5°F PLUS 16 HRS. AT 120°F±10°F.
4. ORIGINAL LENGTH OF SHELL FABRICATED IN MANDREL IS 9.300 IN. THIS LENGTH SHALL BE REDUCED BY 0.100 IN. AT EACH END TO REMOVE IRREGULARITIES.
5. GY70 SHELL AND ALUMINUM RING BONDING SURFACE DIAMETERS SHALL BE CONCENTRIC WITHIN 0.02 IN.



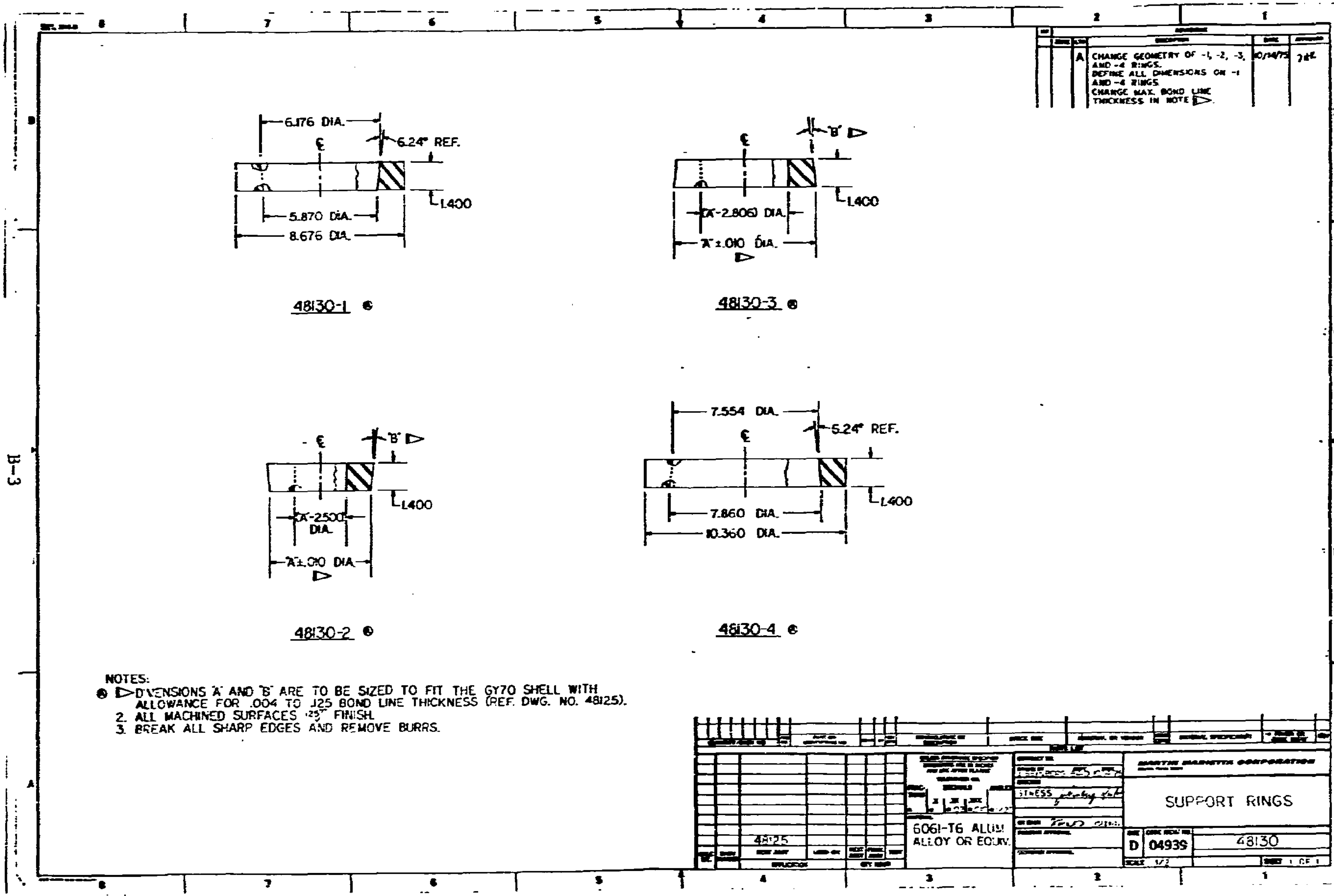


SECTION A-A

MARTIN MARIETTA CORPORATION

GY70/EPOXY CONICAL SHELL

SIZE	CODE IDENT NO.	
D	04939	48125
SCALE 1/2		SHEET 1 OF 1


A CHANGE GEOMETRY OF -1, -2, -3, AND -4 RINGS. DEFINE ALL DIMENSIONS ON -1 AND -4 RINGS. CHANGE MAX. BOND LINE THICKNESS IN NOTE
6.176 DIA.
6.24° REF.
1.400
5.870 DIA.
8.676 DIA.
48130-1
'B'
1.400
'A'-2.806 DIA.
'A' ±.010 DIA.
48130-3
'B'
1.400
'A'-2.500 DIA.
'A'±.010 DIA.
48130-2
7.554 DIA.
5.24° REF.
1.400
7.860 DIA.
10.360 DIA.
48130-4
NOTES:
DIMENSIONS 'A' AND 'B' ARE TO BE SIZED TO FIT THE GY70 SHELL WITH ALLOWANCE FOR .004 TO .125 BOND LINE THICKNESS (REF. DWG. NO. 48125).
2. ALL MACHINED SURFACES 125 FINISH.
3. BREAK ALL SHARP EDGES AND REMOVE BURRS.
48125
6061-T6 ALUM ALLOY OR EQUIV.
STRESS
SUPPORT RINGS
D
04939
48130
1/2

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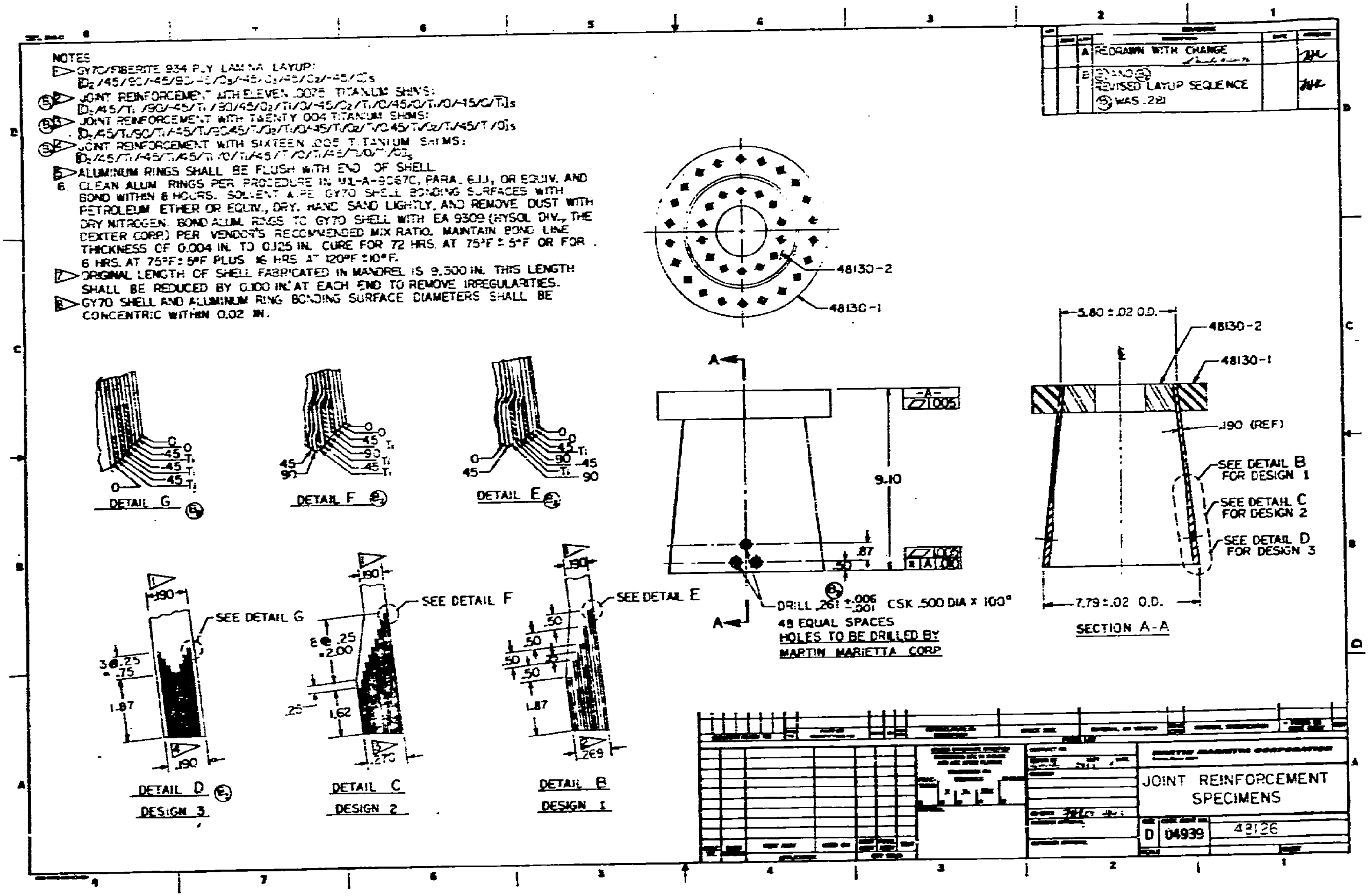
APPENDIX C

JOINT REINFORCEMENT SPECIMENS -
48126 Rev. B


NOTES
1. GY70/FIBERITE 934 PLY LAMINA LAYUP:
[0₂/45/90/-45/90/-45/0₃/-45/0₃/45/0₂/-45/0]s
2. JOINT REINFORCEMENT WITH ELEVEN .0075 TITANIUM SHIMS:
[0₂/45/Ti/90/-45/Ti/90/45/0₂/Ti/0/-45/0₂/Ti/0/45/0/Ti/0/-45/0/Ti]s
3. JOINT REINFORCEMENT WITH TWENTY .004 TITANIUM SHIMS:
[0₂/45/Ti/90/Ti/-45/Ti/90/45/Ti/0₂/Ti/0/-45/Ti/0₂/Ti/0/45/Ti/0₂/Ti/-45/Ti/0]s
4. JOINT REINFORCEMENT WITH SIXTEEN .005 TITANIUM SHIMS:
[0₂/45/Ti/-45/Ti/45/Ti/0/Ti/-45/Ti/0/Ti/45/Ti/0/Ti/0₂]s
5. ALUMINUM RINGS SHALL BE FLUSH WITH END OF SHELL.
6. CLEAN ALUM RINGS PER PROCEDURE IN MIL-A-9067C, PARA. 6.1.1, OR EQUIV. AND BOND WITHIN 6 HOURS. SOLVENT WIPE GY70 SHELL BONDING SURFACES WITH PETROLEUM ETHER OR EQUIV., DRY. HAND SAND LIGHTLY, AND REMOVE DUST WITH DRY NITROGEN. BOND ALUM. RINGS TO GY70 SHELL WITH EA 9309 (HYSOL DIV., THE DEXTER CORP.) PER VENDOR'S RECOMMENDED MIX RATIO. MAINTAIN BOND LINE THICKNESS OF 0.004 IN. TO 0.125 IN. CURE FOR 72 HRS. AT 75°F ± 5°F OR FOR 6 HRS. AT 75°F ± 5°F PLUS 16 HRS AT 120°F ± 10°F.
7. ORIGINAL LENGTH OF SHELL FABRICATED IN MANDREL IS 9.500 IN. THIS LENGTH SHALL BE REDUCED BY 0.100 IN. AT EACH END TO REMOVE IRREGULARITIES.
8. GY70 SHELL AND ALUMINUM RING BONDING SURFACE DIAMETERS SHALL BE CONCENTRIC WITHIN 0.02 IN.
A REDRAWN WITH CHANGE
B REVISED LAYUP SEQUENCE
WAS .281
48130-2
48130-1
A
9.10
.87
.50
DRILL .261 +.006 -.001 CSK .500 DIA x 100°
48 EQUAL SPACES
HOLES TO BE DRILLED BY MARTIN MARIETTA CORP
5.80 ± .02 O.D.
.190 (REF)
SEE DETAIL B FOR DESIGN 1
SEE DETAIL C FOR DESIGN 2
SEE DETAIL D FOR DESIGN 3
7.79 ± .02 O.D.
SECTION A-A
DETAIL G
DETAIL F
DETAIL E
SEE DETAIL G
SEE DETAIL F
SEE DETAIL E
.190
3 @ .25 = .75
1.87
8 @ .25 = 2.00
.25
1.62
.270
.50
.269
DETAIL D
DESIGN 3
DETAIL C
DESIGN 2
DETAIL B
DESIGN 1
MARTIN MARIETTA CORPORATION
JOINT REINFORCEMENT SPECIMENS
D 04939 48126

APPENDIX D

TEST PROCEDURES FOR GY70/EPOXY BASIC CONICAL SHELL SPECIMENS

Axial Compression Testing of GY/70 Epoxy Concial Shell
(Test 1; Conical Shell 004 and Test 6; Conical Shell 006)

1.0 TEST OBJECTIVES

These tests were performed to determine the compressive strength and modulus of the GY70/Epoxy Conical Shell under axial compression load. Results were correlated with analytical predictions. Additionally, this test serves as a qualification test for the fabricated part. Two frusta were tested under similar conditions. The two test procedures differed only in that 21 strain gases were used in Test 1 (Conical Shell 004) and 11 strain gases were used in Test 6 (Conical Shell 006).

2.0 TEST DESCRIPTION

2.1 Hardware Configuration

The GY70/Fiberite 934 conical shells, part number 48125, were 9.1 inches long with forward and aft shell outside diameters of 5.80 inches and 7.79 inches respectively. The nominal shell thickness is 0.19 inches. At each end of the shell inner and outer aluminum rings of 6061-T652, 1.4 inches thick were bonded to the shell surfaces with Hysol adhesive EA9309. The aluminum rings are installed to stabilize the end laminates from crippling or fraying under localized loadings. The rings are sufficiently rugged so that they can be reused for the subsequent shell specimens.

2.2 Load Conditions

The shells were loaded in compression by means of a 200 KIPS hydraulic jack. Steel loading plates were used to insure uniform load distribution and apply load directly to the ends of the graphite/epoxy shell. There was no gap between the loading plate and the shell wall.

2.3 Test Arrangement

2.3.1 Facility

The tests were performed in the static test area of the mechanical laboratories, Martin Marietta Corporation, Orlando, Florida. The following equipment was used to conduct the test:

a) 200K hydraulic jack (1), Messinger

b) 100K load cell (2), BLH

c) Series 800 strain indicator (1), BLH

d) Switch & Balance Unit (1), BLH

e) Speed-O-max load cell indicator (2)

f) Pressure gage (1), 10,000 psi maximum

g) Direct Current Displacement Transducers (DCDT) (2)

h) Hand pumps (1), Blackhawk.

2.3.2 Mechanical Test Assembly

The GY70/Epoxy shell specimens (48125) were placed between the two steel load plates, and the assemblies were installed upright on top of the 200K hydraulic jack with the shaft extending through the center of the assembly. A steel yoke was threaded on to the shaft to secure the assembly.

The test arrangement is shown in Figure 1. Loads were monitored by use of a pressure gage which is calibrated prior to testing by means of a load cell.

2.3.3 Instrumentation

2.3.3.1 Strain Measurement

Test 1 - Conical Shell 004

Twenty-one axial type strain gages (FAE 25S-12S6) were installed at three stations on the test specimen: one halfway between the ends of the specimen, one 0.40 inches from the small end support ring and one 0.40 inches from the large end support ring. Eleven strain gages were installed at the station halfway between the specimen ends at 120° intervals around the circumference. Seven gages were installed on the outside surface and four gages on the inside surface. A pair of gages (longitudinal and circumferential) were placed at each location and one circumferential gage were placed on an outside seam near one of the strain gage pairs. The inner surface gages were located back-to-back with two of the three pairs on the outer surface. At each of the two stations near the end rings five gages were installed. At each station two pairs of gages were placed at 180° intervals around the circumference on the outside surface and one longitudinal gage was placed on the inside surface. The inner surface gage was back-to-back with one outer surface strain gage pair. The gages at the large end station were staggered by 90° relative to those at the small end station. All strain gage locations are shown in Figure 2.

Test 6 - Conical Shell 006

Eleven axial type strain gages (FAE 25S-12S6) were installed at three stations on the test specimen: one halfway between the ends of the specimen, one 0.40 inches from the small end support ring and one 0.40 inches from the large end support ring. Three strain gages were installed at the station halfway between the specimen ends at 120° intervals around the circumference. At each of the two stations near the end rings four gages were installed. At each of these stations, gages were placed at 180°

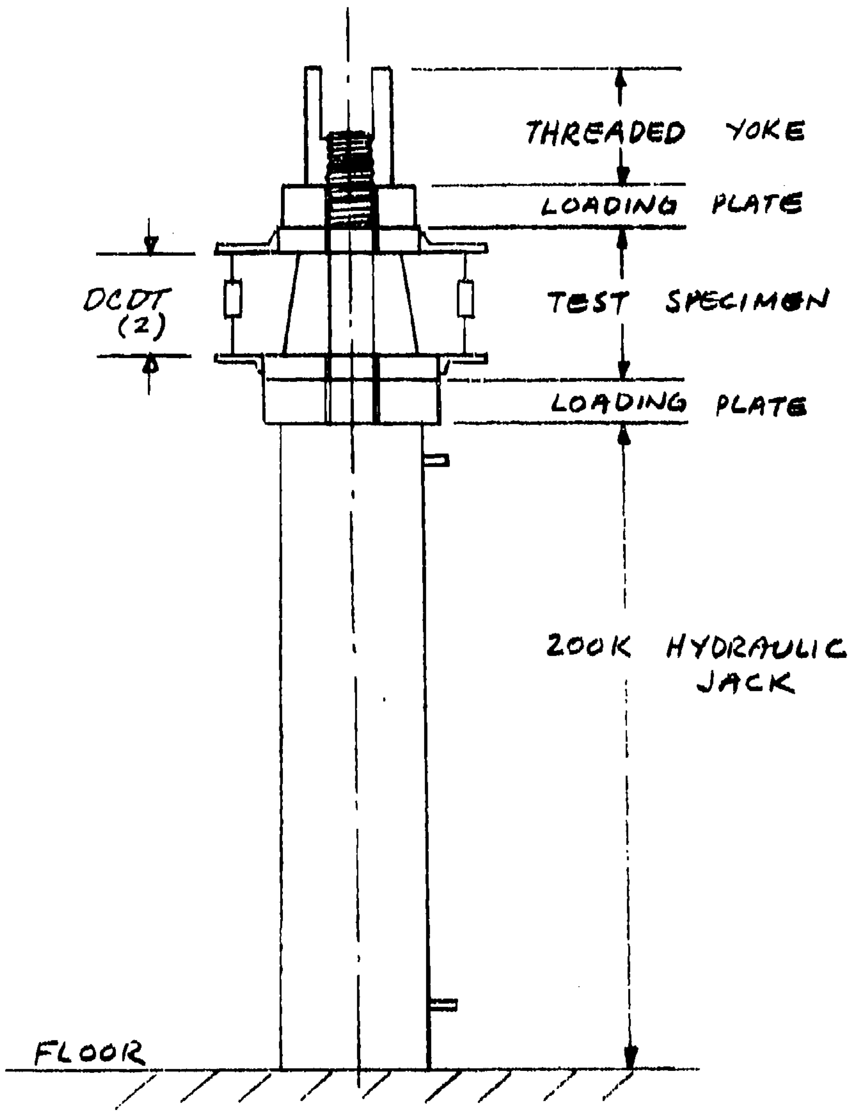


FIG. 1 GY70/EPOXY SHELL

COMPRESSION TEST SET-UP

TEST 1 — CONICAL SHELL 004

TEST 6 — CONICAL SHELL 006

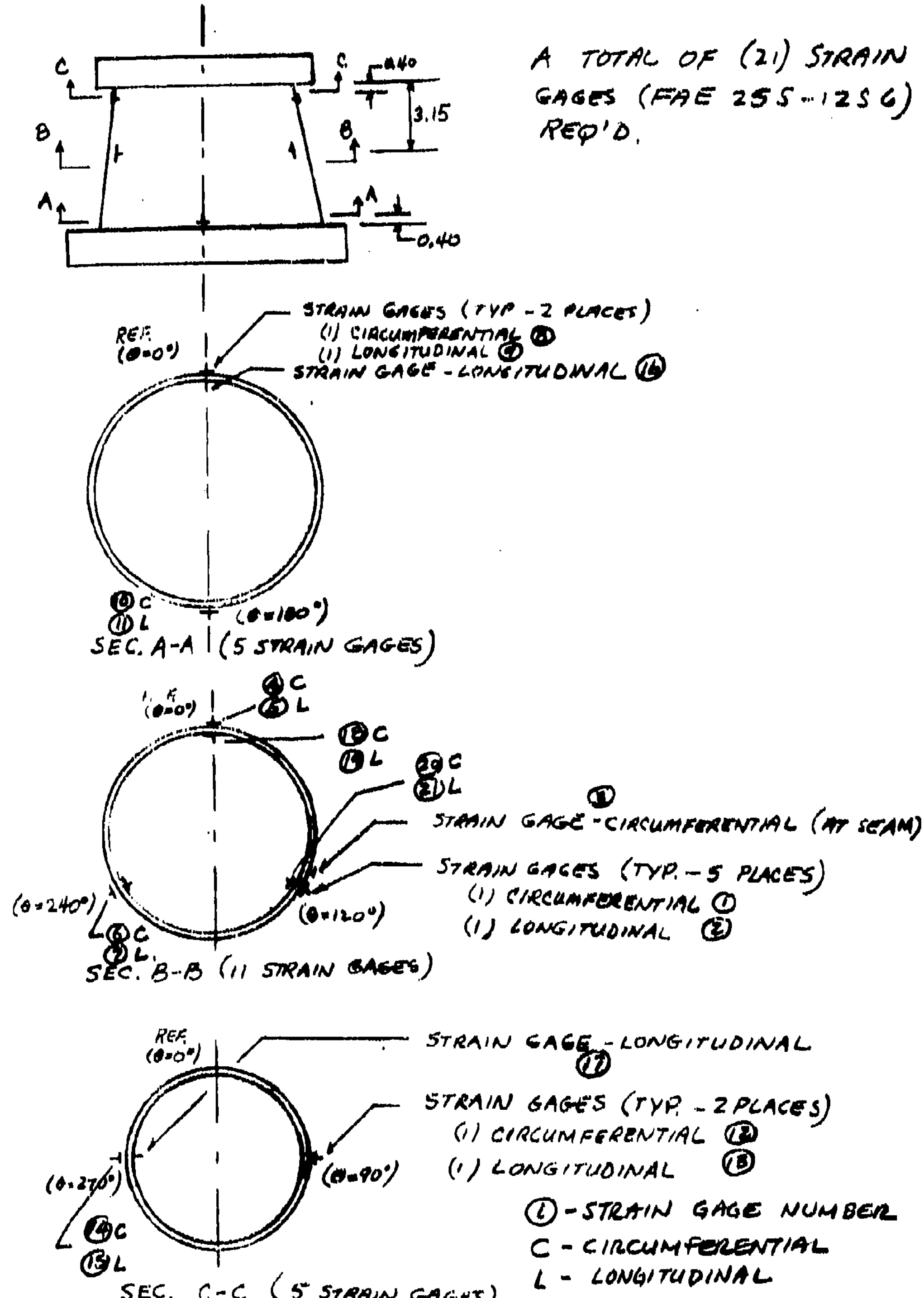


FIG. 2 - STRAIN GAGE LOCATIONS FOR TEST 1

intervals around the circumference on the outside and inside surfaces. The gages at the large end station were staggered by 90° relative to those at the small end station. All strain gage locations are shown in Figure 3.

2.3.3.2 Deflection Measurements

Two DCDT's located diametrically opposite from the shell specimen were used to measure the overall axial displacement of the shell under axial compression loading. The data were correlated with the analytical predictions.

3.0 TEST PROCEDURES

The GY70/Epoxy conical shell compression tests were conducted as follows:

a) The tests were setup as described in the foregoing sections and performed in accordance with Figure 1.

b) Designated project personnel inspected the test setup and photos were taken.

c) The load, strain and dial indicators were adjusted to read zero.

d) 5000 lbs. preload was applied and the setup was checked for proper operation. All strain and deflection readings were recorded.

e) The load was removed and all instrumentations were recorded.

f) All readings were adjusted to zero.

g) Loads were applied in the following increments:

10,000 lbs. increments to 100,000 lbs.

5,000 lbs. increments from 100,000 to 200,000 lbs

All instrumentations were recorded at each load increment.

h) Failure load was recorded at 160,000 lbs. for Test 1 and at 180,000 lbs. for Test 6.

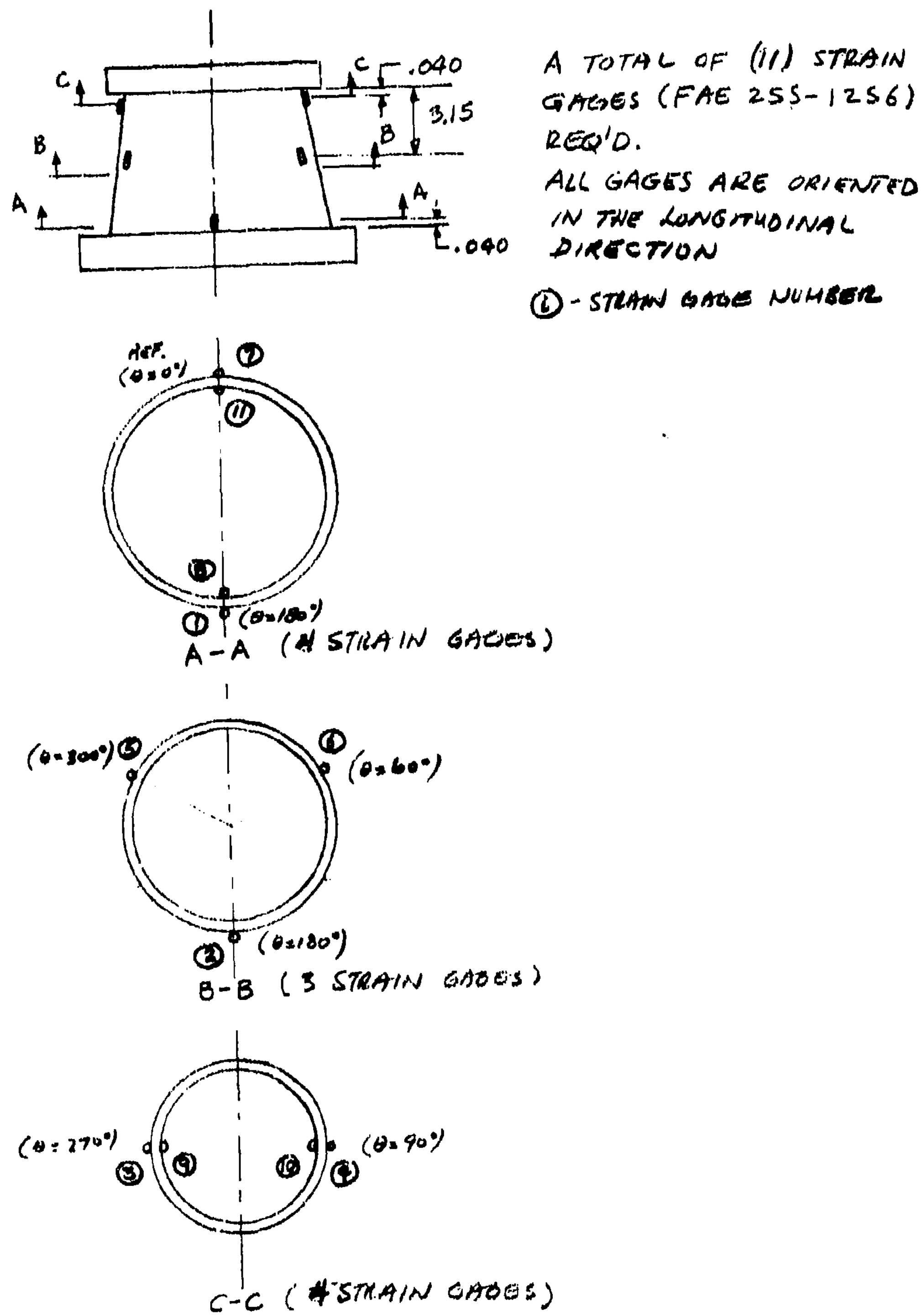


FIG. 3 STRAIN GAGE LOCATIONS FOR TEST 6

GY70/Epoxy Conical Shells

Shear/Bending Test (Test 2; Conical Shell 001)

1.0 TEST OBJECTIVE

The test was performed to determine the load carrying capability of the conical shell under a cantilevered load. This basic strength data for the shell will be used in the evaluation of the strength in the combined loading condition. It is essential that the strength of the multi-layered GY70/Epoxy conical shell can be predicted for the basic loading conditions for a given type of fabrication technique.

2.0 TEST DESCRIPTION

2.1 Hardware Configuration

The GY70/Fiberite 934 conical shell, part number 48125, is 9.1 inches in length with 5.80 inches diameter at the small end and 7.79 inches diameter at the large end. The nominal shell thickness is 0.19 inch. Inner and outer rings of 6061-7652 aluminum alloy are bonded to the shell with Hysol adhesive EA9309. Holes are drilled in the rings for attachments of the specimen to the test and loading fixtures. The rings are sufficiently rugged so that they can be reused for the subsequent shell specimens.

2.2 Load Condition

A load transverse to the shell axis was applied at the forward loading fixture by a 100K hydraulic jack. This single cantilevered load allowed direct correlation of test data and analytical results.

2.3 Test Arrangement

2.3.1 Facility

The test was performed in the static test area of the Mechanical Laboratory, Martin Marietta Corporation, Orlando, Florida.

The following equipment was used to conduct the test:

a) 100K hydraulic jack (1), Messinger

b) 100K load cell (1) BLH.

c) Series 800 strain indicator (1) BLH.

d) Switch and Balance unit (1) BLH.

e) Direct Current Differential Transducers (4).

f) Speed-o-max load cell indicator (1).

g) Hand pump (1) Blackhawk.

2.3.2 Mechanical Test Assembly

The GY70/Epoxy shell specimen (48125) was bolted at the larger end to a test fixture with 46 5/16 inch diameter steel bolts (150 ksi) torqued to 150 in-lbs. (2,000 lbs. preload). The forward end of the specimen was bolted to a loading fixture with 36 5/16 inch diameter steel bolts (150 ksi) torqued to 150 in-lbs. (2,000 lbs. preload). The assembly was cantilevered from a load reacting structural column. The 100K hydraulic jack was attached to the loading lug of the fixture at the forward end of the specimen as shown in Figure 4.

2.3.3 Instrumentation

2.3.3.1 Strain Measurements

A total of eighteen axial type strain gages (FAE 25S-12S6) were installed on the shell specimen. Eight were located at a station midway between the ends of the specimen at points of maximum strains. The other ten were installed on the shell adjacent to the fixed end where the maximum bending moment occurs and also the maximum local shell bending takes place. The locations are shown in Figure 5. The strain measurements were correlated with analytical results.

2.3.3.2 Deflection Measurements

One DCDT located at the cantilevered end of the shell specimen was used to measure the deflection of the free end under the transverse load. The other three DCDT's were used to measure ground support structure deflections at the fixed end of the specimen. The locations are shown in Figure 4. The data were used to correlate with the analytical predictions.

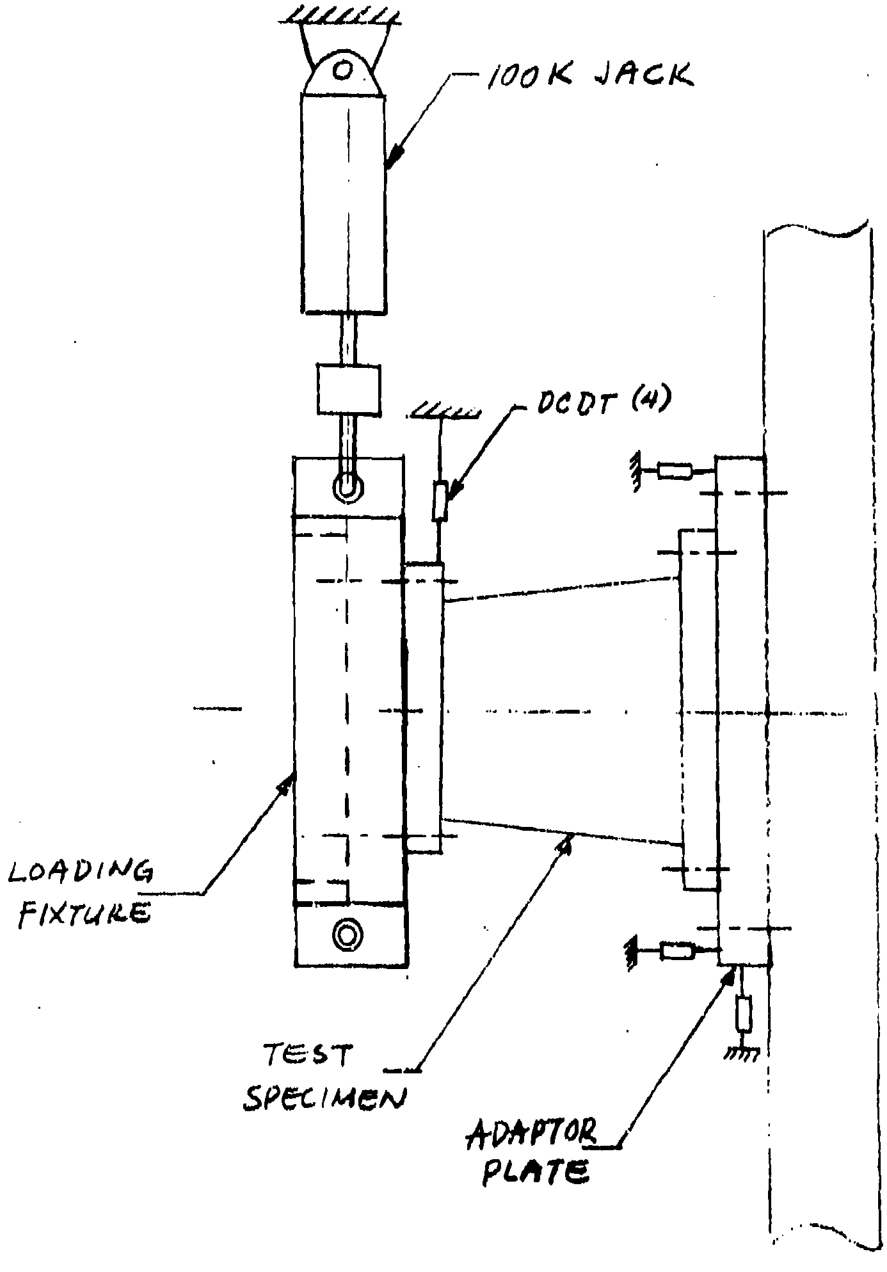


FIG 4. TEST SET-UP FOR TEST 2

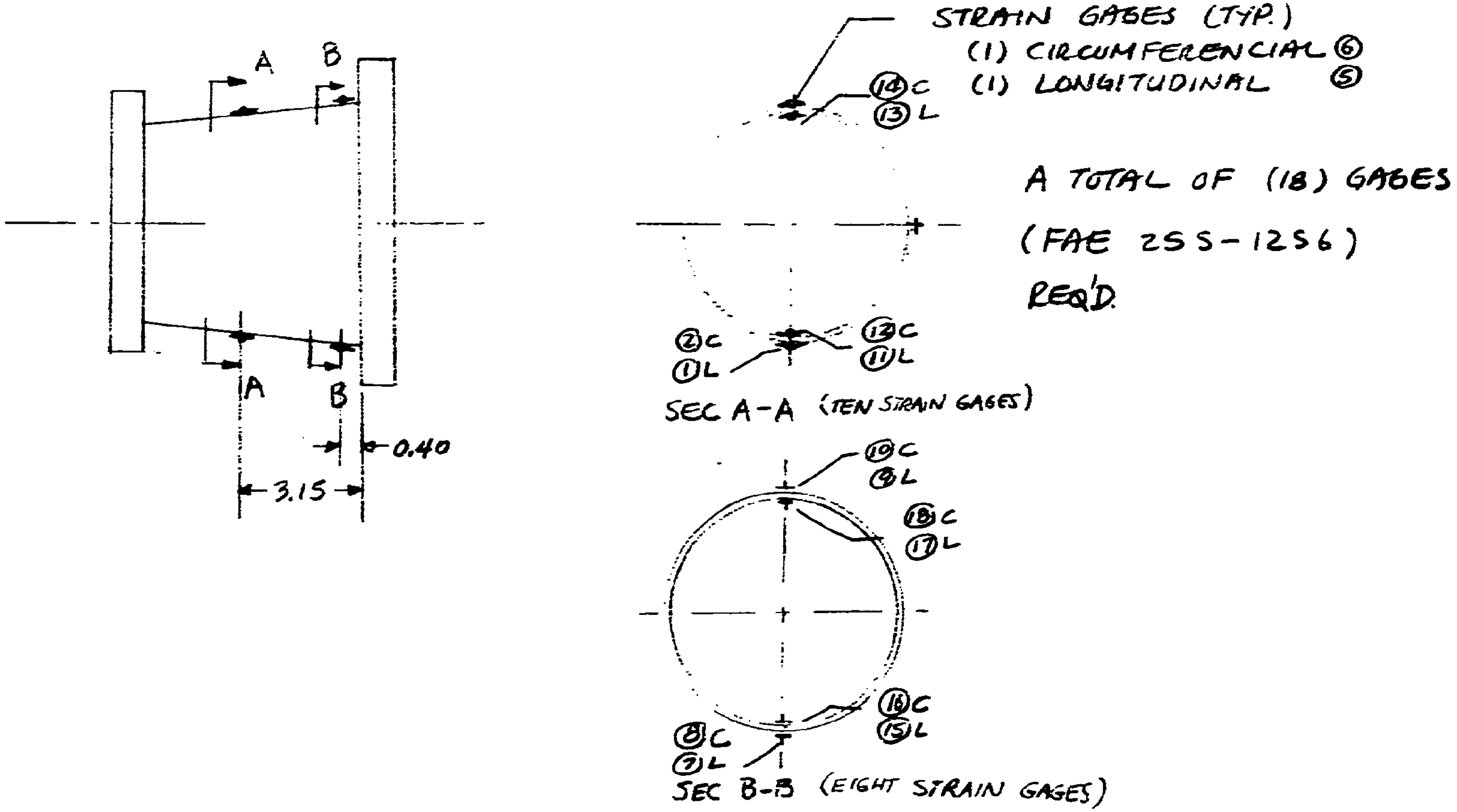


FIG. 5 STRAIN GAGE LOCATIONS FOR TEST 2

3.0 TEST PROCEDURE

The GY70/Epoxy conical shell shear/bending test was conducted as follows:

a) The test was setup as described in the foregoing sections and in accordance with Figure 4.

b) Designated project personnel inspected the test setup. Photos were taken.

c) The load, strain and dial gage readings were adjusted to zero.

d) 2,000 lbs. preload was applied and instrumentation readings were checked.

e) The load was removed and all instrumentations were recorded.

f) All instrumentation was abjusted to zero at zero load.

g) Loads were applied in the following increments:

   2,000 lbs. increments to 20,000 lbs.

   All instrumentations were recorded at each load increment.

h) Failure load was recorded at 20,000 lbs.

Combined Loading Test (Tests 3, 4, 5, 7, 8, 9 and 10; Conical Shells 002, 003, 005, 007, 008, 009 and 010)

1.0 TEST OBJECTIVES

The tests were performed to verify the design and fabrication of the conical shells under combined design load conditions. The test results were correlated with the analytical prediction. The effect of variations of the ply angles due to the gore pattern layup on the strength and stiffness of an idealized laminated shell can be evaluated from the test results. In addition, a combined load interaction diagram was established by holding one loading constant and increasing the other loads.

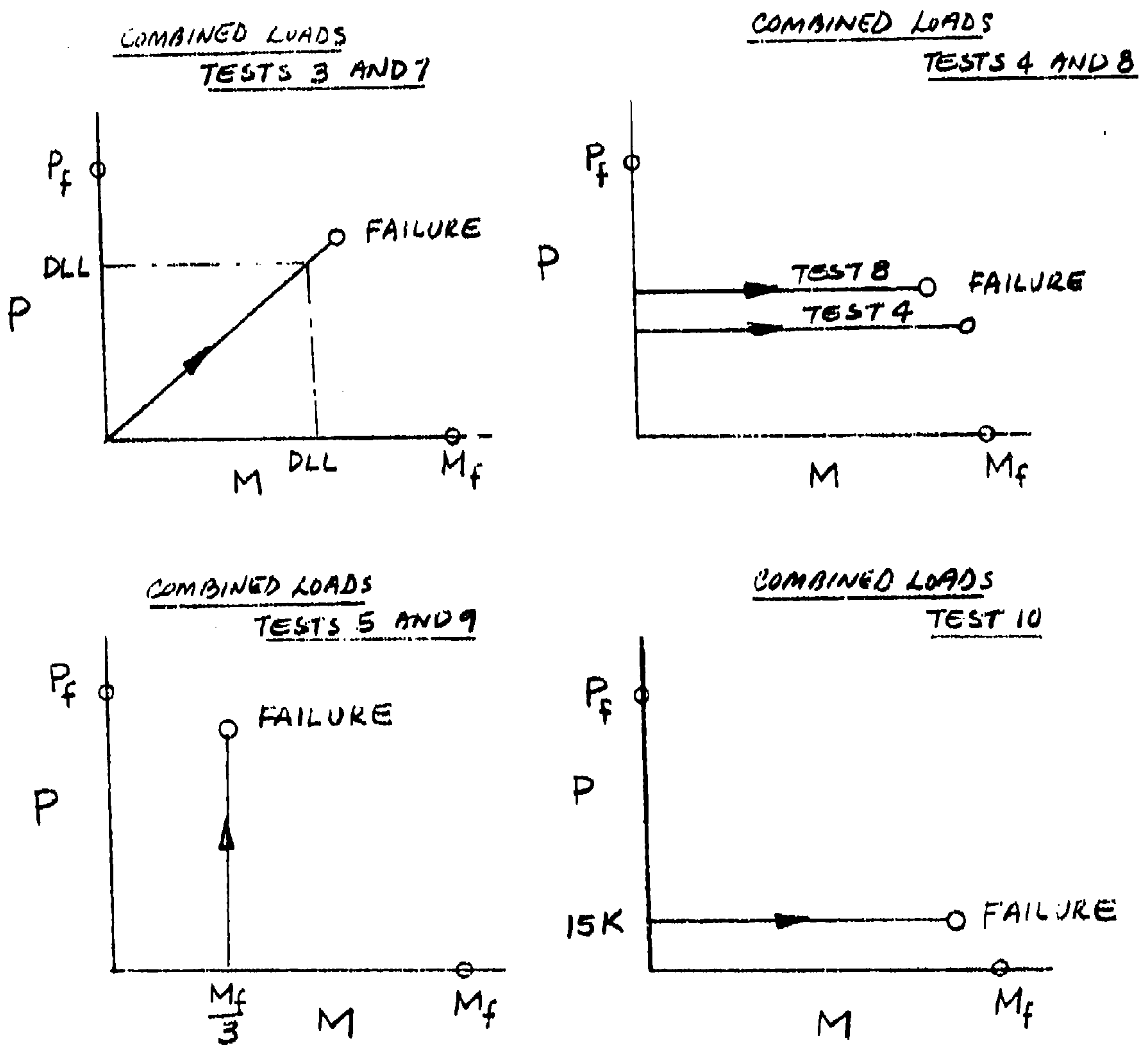
2.0 TEST DESCRIPTION

2.1 Hardware Configuration

The GY70/Fiberite 934 conical shell, part number 48125, is 9.1 inches in length with 5.80 inches diameter at the small end and 7.79 inches diameter at the large end. The nominal shell thickness is 0.19 inch. Inner and outer rings of 6061-T652 aluminum alloy are bonded to this shell with Hysol adhesive EA9309. Holes are drilled in the rings for attachments of the specimen to the test and loading fixtures. The rings are sufficiently rugged so that they can be reused for the subsequent shell specimens.

2.2 Load Condition

Each of the specimens to be tested under the combined loading was loaded with a particular loading path. The objective was to obtain failure points to define a combined load failure surface. Two basic types of loading to be considered are axial compression and bending moment. The four loading paths are shown graphically as follows:



P_f and M_f are failure loads established from the compression test and shear bending test respectively where each is subjected to a single loading. DLL designates Design Limit Loads which are given in the following:

P (axial compression) = 19,100 lbs.

M (bending moment at fixed end) = 158,000 in-lbs.

2.3 Test Arrangement

2.3.1 Facility

The tests were conducted in the static test area of the Mechanical Laboratory, Martin Marietta Corporation, Orlando, Florida.

The following equipment were used to conduct the test:

a) 100K hydraulic jack (2) messinger.

b) 20K hydraulic jack (2) messinger.

c) 100K load cell (2) BLH.

d) 20K load cell (2) BLH.

e) Speed-o-max load cell indicator (4).

f) Series 800 strain indicator (1) BLH.

h) Direct Current Differential Transducers (4).

i) Hand pump (4) Blackhawk.

2.3.2 Mechanical Assembly

The GY70/Epoxy shell specimens (48125) were bolted at the larger end to the test fixture with 46 5/16 inch diameter steel bolts (150 ksi) torqued to 150 in-lb. (2,000 lb. preload). The forward ends (smaller end) were bolted to a loading fixture with 36 5/16 inch diameter steel bolts (150 ksi) torqued to 150 in-lbs. (2,000 lbs. preload).

Two hydraulic jacks positioned parallel to the shell axis loaded the two lugs on the loading fixture. The third lug accommodated the jack which was placed transverse to the shell axis. A whiffle tree arrangement was fastened to the straps which were wrapped around the conical shell. A hydraulic jack applied load to the whiffle tree and in turn loaded up the shell simulating the external pressure loading.

The mechanical test assembly is shown in Figure 6.

2.3.3 Instrumentation

2.3.3.1 Strain Measurements

A total of eighteen axial type strain gages (FAE 25S-12S6) were installed on each shell specimen. For tests 3, 4, and 5 eight gages were located at a station midway between the ends of the specimen at points of maximum strains, and ten were installed on the shell adjacent to the fixed end where the macimum-bending moment occurs and also the maximum local shell bending takes place. The locations are shown in Figure 7. For tests 7, 8, 9 and 10, the strain gages were relocated to cover the strain measurement at the small end. Six gages were located at a station midway between the ends of the specimens, six were installed near the small end and six were installed on the shell adjacent to the fixed end where the maximum bending moment occurs. The locations are shown in Figure 8.

The strain measurements were used in correlation with analytical results.

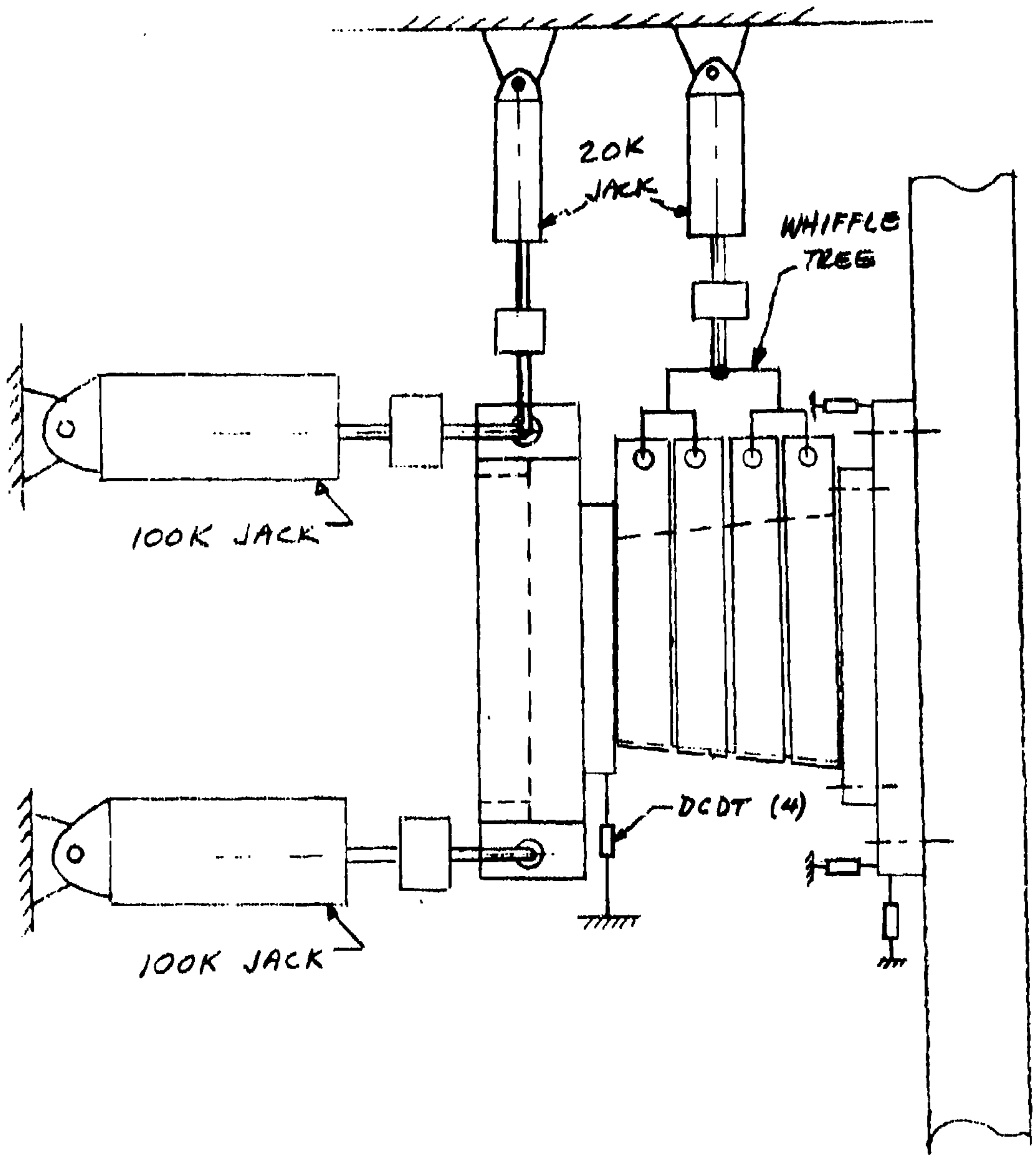


FIG 6 TEST SET-UP (TESTS 3, 4, 5, 7 8, 9 AND 10)

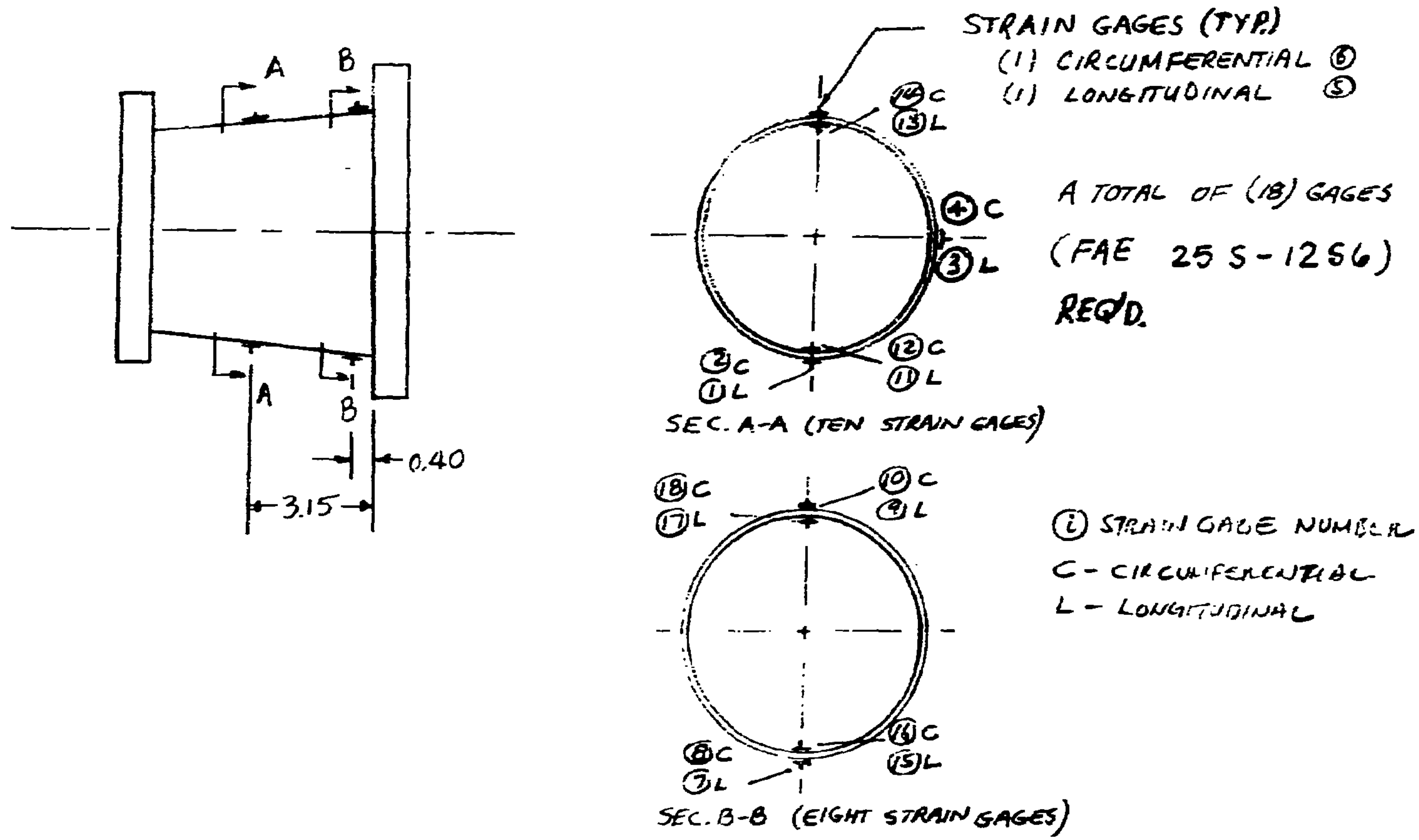


FIG. 7 STRAIN GAGE LOCATIONS FOR TESTS 3, 4 AND 5

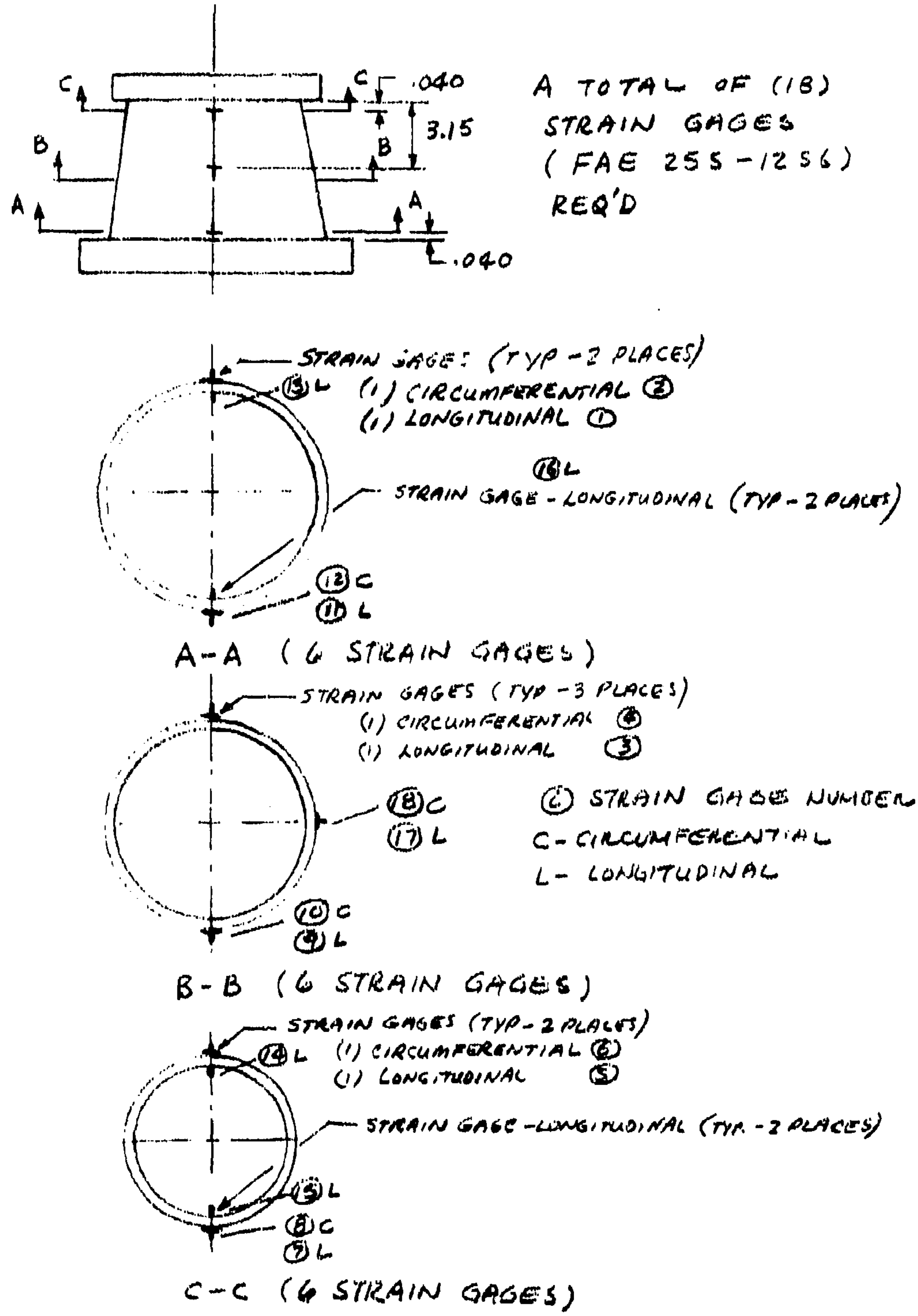


FIG. 8 STRAIN GAGE LOCATIONS - TESTS 7, 8 9 AND 10

2.3.3.2 Deflection Measurements

One DCDT located at the cantilevered end of the shell specimen was used to measure the deflection of the free end under the transverse load. The other three DCDT's were used to measure ground support structure deflections at the fixed end of the specimen. The locations are shown in Figure 6. The data were used to correlate with the analytical predictions.

3.0 TEST PROCEDURE

The GY70/Epoxy conical shell combined load tests were conducted as follows:

a) Tests were setup as described in the foregoing sections and in accordance with Figure 6.

b) The test setup was inspected by designated project personnel. Photos were taken of the setup.

c) The load, strain and dial gage readings were adjusted to zero.

d) 10 percent of the design limit loads were applied simultaneously and the setup was checked for indications of mechanical interference in loading apparatus and proper operation of instrumentations. All instrumentation readings were recorded.

e) All loads were removed and all instrumentations were recorded.

f) All instrumentation was adjusted to zero at zero load.

Combined Loads Tests 3 and 7

g) Loads were applied in the following percentages of design limit load (see Section 2.2) 20, 40, 50, 60, 70, 80, 90, 100, 20, 0 All instrumentation at each loading was recorded.

h) The test specimen was visually inspected for cracks, delamination or indications of permanent deformation. Results of inspection were recorded.

i) The following percentages of design limit load were reapplied until failure occured. 0, 20, 40, 50, 60, 70, 80, 90, 100, 120, 130,---

j) Failure loads were recorded.

Combined Loads Tests 4 and 8

g) Axial compression equal to 1/2 of P_f (80,000 lbs.) and 53,334 lbs. were applied to tests 8 and 4 respectively.

h) All instrument readings were recorded.

i) The axial compression load was held constant and all other loads were applied at the following percentage of design limit load until failure: 0, 20, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130. All instrumentation at each load increment was recorded.

Combined Loads Tests 5 and 9

g) Equal percent of Design Limit Load was applied in shear and bending moment so that the fix-end moment was equal to 1/3 M_f (64,667 in-lb).

h) All instrumentation was recorded.

i) Shear and bending moment were held constant and axial compression was applied at increments of 20 percent of design limit load until failure occurred at 103,000 lbs. for test 5 and 137,000 lbs. for test 9. All instrumentations were recorded at each load increment.

Combined Loads Test 10

g) An axial compression load of 15,000 lbs. was applied.

h) All instrumentation was recorded.

i) Axial compression load was held constant and all other loads were applied at the following percentage of design limit load until failure: 0, 20, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130. All instrumentation at each load increment was recorded.

APPENDIX E

TEST PROCEDURES FOR JOINT REINFORCEMENT SPECIMENS

Shock Testing of Type I Joint Reinforcement Frusta (Tests 1A and 2A; Shells 01R and 02R)

1.0 TEST OBJECTIVE

The tests were performed to evaluate the load carrying capabilities of the joint reinforcement for the GY70/Epoxy frusta under shock loading and to determine the modes of failure.

2.0 TEST DESCRIPTION

2.1 Hardware Configuration

The GY70/Fiberite 934 frustum with joint reinforcement at the large end, part number 48126A, is a section 9.1 inches long with forward and aft shell outside diameters of 5.80 inches and 7.79 inches respectively. Eleven (11) .0075 titanium shims are interleaved with the thirty eight (38) GY70/Epoxy plies for reinforcement in the region of the screw holes. The shock test frustums do not have the aluminum rings (48130-1 and 48130-2) installed so that the dynamic response of the frustum can be better simulated under the test condition. Two rows of .281 inches diameter holes with staggered pattern are designed to transfer the shock loads to the shell through 1/4 inch countersunk screws.

2.2 Load Conditions

The graphite/epoxy frustum was bolted to a test fixture through the 48 countersunk holes. The test fixture was fastened to the shock machine at its base. The smaller end of the frustum stands free. The test fixture is designed such that the loads are transmitted to the frustum through the 48 radial screws. Figure 1 shows the frustum and test fixture in relation to the shock machine.

The shock machine (SM-1000) applied shock pulses to the specimen to produce the shock environments as shown in Figure 2. In order to determine the fragility level of the reinforced joint, the acceleration magnitudes of the test environment were increased at successive shock pulses. The shock machine was calibrated so that the increments in acceleration magnitudes corresponded to those shown in the shock spectra (Figure 2).

The shock loading simulated the stage separation shock. The maximum separation shock spectrum shown in Figure 2 is based on cutting steel with a charge of 50 grain's per foot at 5 inches away from the splice joint. The splice joint of the guidance and control section of ATI is located 122 inches forward of the separation joint, therefore, the shock level is attenuated to a much lower level as shown by the estimated G&C splice shock of Figure 2. This splice shock spectrum was verified prior to testing of the frustum.

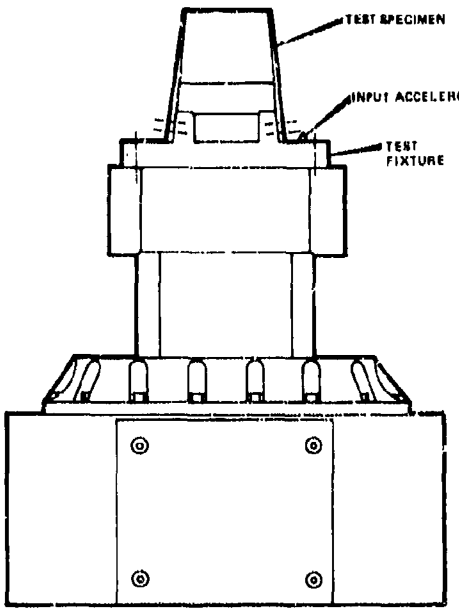


Figure 1. SM-1000 Shock Machine with Frustrum in Test Mode

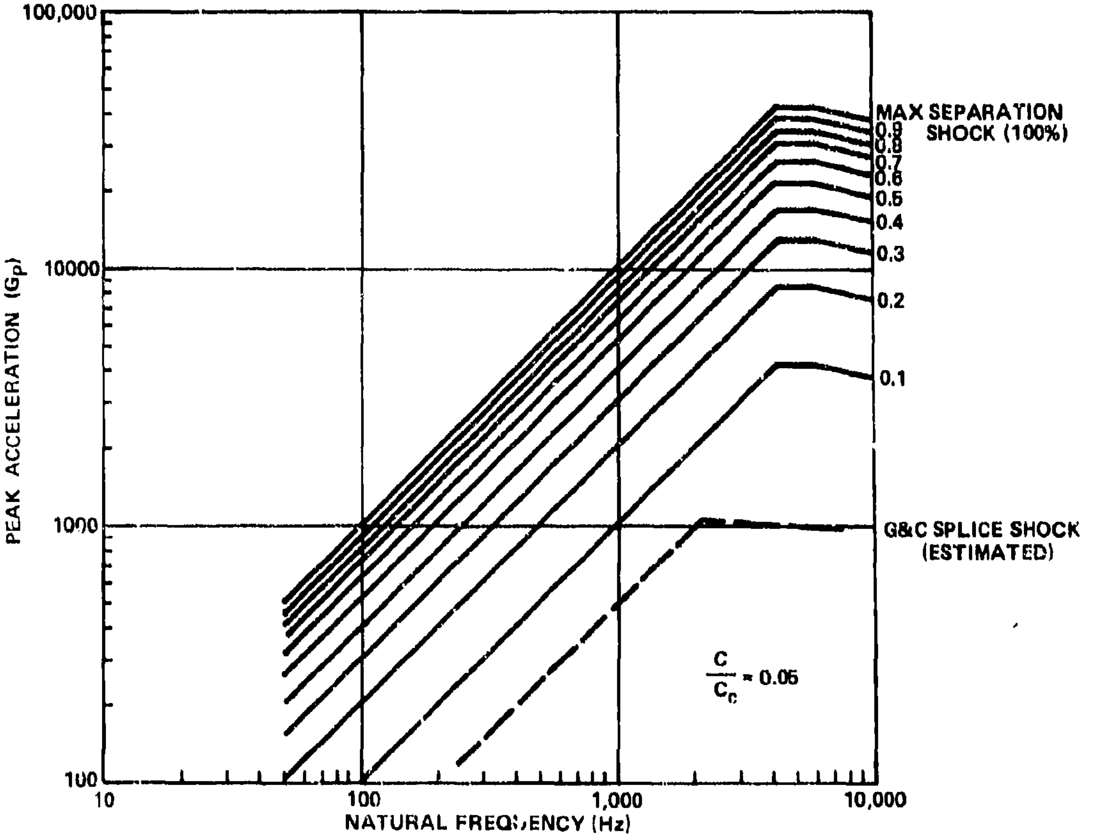


Figure 2. Shock Spectra Simulating Stage Separation Shock

2.3 Test Arrangement

2.3.1 Facility

The test was performed in the dynamic test area of the Mechanical Test Laboratories, Martin Marietta Corporation, Orlando, Florida. The following equipment was used to conduct the test:

a) SM-100 shock machine
b) Charge amplifiers
c) Magnetic tape recorders
d) Shock spectrum analyzer
e) Oscillograph.

2.3.2 Mechanical Test Assembly

The GY70/Epoxy frustum was fastened to the test fixture at the reinforced end with forty-eight 1/4-inch diameter screws. The test fixture was bolted to the moving anvil of the shock machine. The SM-1000 shock machine with the test specimen in place is shown in Figure 1.

2.3.3 Instrumentation

2.3.3.1 Strain Measurements

Twelve axial type strain gages were installed on the test specimen. Six gages were located on the outside surface of the shell equally spaced around the circumference at 4.37 inches from the reinforced end. Four gages were placed on the inside surface equally spaced. The other two gages were located on the outside surface along the meridian of the shell as depicted in Figure 3. The gages were oriented to measure the longitudinal strains of the shell. The location of the strain gages are shown in Figure 3. The strain measurements were recorded on magnetic tape.

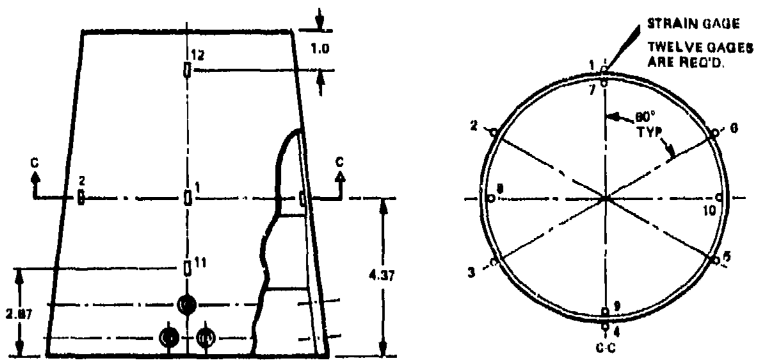


Figure 3. Strain Gage Locations - Shock Tests 1A and 2A

2.3.3.2 Acceleration Measurements

One accelerometer was mounted on the base of the test fixture to measure the acceleration level of the input pulse. The data were used in the shock spectrum analyzer.

3.0 TEST PROCEDURES

The following test sequence was followed in the shock testing of the GY70/Epoxy frustum with joint reinforcement.

a) The bare fixture was secured to the shock machine table. All existing bolts were torqued.

b) The shock input accelerometer was mounted at the base of the fixture and torqued to 28 in/lbs.

c) The system was calibrated to match the 0.1 (10%) shock level. The input shock pulse required was determined using half-sine pulse. The charge pressure, drop height and impacting material required to produce the required shock pulse were recorded.

d) Step c) was repeated to calibrate the system for the other shock environment shown in Figure 2.

e) The test specimen was secured to a fixture on the shock machine table and the 1/4 inch screws were torqued to 75 in/lbs.

f) All instrumentation was checked to insure proper operation.

g) The test specimen was shocked to the G&C splice shock level.

h) The strain-gage data on the oscillograph was reviewed and the specimen was visually inspected for any damage. The results were recorded.

i) Steps g) and h) were repeated at higher shock levels until the maximum shock level (100%) was reached.

Combined Static Loading Test of Type I Joint Reinforcement Frustum (Test 3A; Shell 03R)

1.0 TEST OBJECTIVE

The test was performed to evaluate the structural characteristics and load carrying capabilities of the joint reinforcement design under the combined load conditions. The mode of failure for the specimen was determined.

2.0 TEST DESCRIPTION

2.1 Hardware Configuration

The GY70/Fiberite 934 laminated frustum with joint reinforcement at the large end, part number 48126A, is a section 9.1 inches long with forward and aft shell outside diameters of 5.80 inches and 7.79 inches respectively. Eleven (11) .0075 titanium shims are interleaved with thirty eight(38) GY70/Epoxy plies for reinforcement in the region of the screw holes. Two rows of 0.281 inch diameter holes with staggered pattern are used for attachment of the frustum to the test fixture with 1/4 inch countersunk screws. The two aluminum rings bonded to the shell at the small end are designed to mate with the loading fixture.

2.2 Load Condition

The specimen was tested under a combined and simultaneous loading of axial compression, shear and bending moment. This condition simulates the critical overall load condition represneting loads at booster burnout with 20 percent overshoot. The Design Limit Loads for the half scale G&C frustum are as follows:

P (Axial compression) = 19,000 lbs.
V (shear at fixed end) = 12,000 lbs.
M (bending moment at fixed end) = 158,000 in/lbs.

2.3 Test Arrangement

2.3.1 Facility

The test was conducted in the static test area of the Mechanical Laboratory, Martin Marietta Corporation, Orlando, Florida.

The following equipment was used to conduct the test:

a) 100K hydraulic jack (2) Messinger
b) 20K hydraulic jack (2) Messinger
c) 100K load cell (2) BLH
d) 20K load cell (2) BLH
e) [illegible]-o-max load cell indicator (4)
f) Series 800 strain indicator (1) BLH
g) Switch and Balance Unit (1) BLH
h) Direct Current Differential Transducers (4)
i) Hand pump (4) Blackhawk.

2.3.2 Mechanical Assembly

The GY70/Epoxy frustum was fastened to the test fixture at the reinforced end with forty-eight 1/4-inch diameter screws. The aluminum rings at the other end were bolted to a loading fixture with thirty-six 5/16-inch bolts (150 ksi) torqued to 150 in/lbs.

Two hydraulic jacks positioned parallel to the shell axis loaded the two lugs on the loading fixture. The third lug accommodated the jack placed transverse to the shell axis. A whiffle tree arrangement was attached to the straps which were wrapped around the frustum. A hydraulic jack applied load to the whiffle tree which in turn loaded up the shell simulating the external pressure loading. The mechanical test assembly is shown in Figure 4.

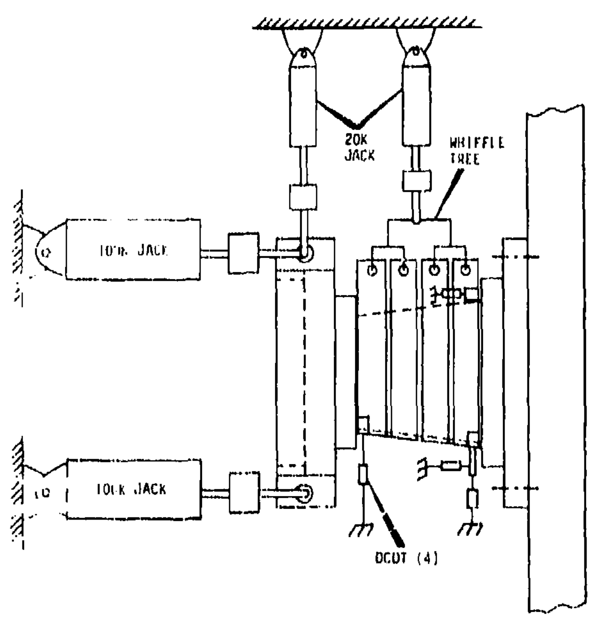


Figure 4. Test Set-Up for Test 3A

2.3.3 Instrumentation

2.3.3.1 Strain Measurements

A total of sixteen (16) axial type strain gages (FAE 25S-12S6) were installed on the shell specimen. Four were located in the constant thickness section of the shell to measure the maximum longitudinal shell strains. The other twelve were located in the close proximity of the splice screws to measure the local longitudinal and hoop strains. The locations of all the strain gages are shown in Figure 5.

2.3.3.2 Deflection Measurements

One DCDT located at the cantilevered end of the shell specimen was used to measure the deflection of the free end under load. The other three DCDT's were used to measure hee test fixture deflections at the fixed end of the specimen. The true deflection of the specimen can be obtained from the measurements. The locations of the DCDT's are shown in Figure 4.

3.0 TEST PROCEDURE

The GY70/Epoxy frustum combined load test was conducted as follow:

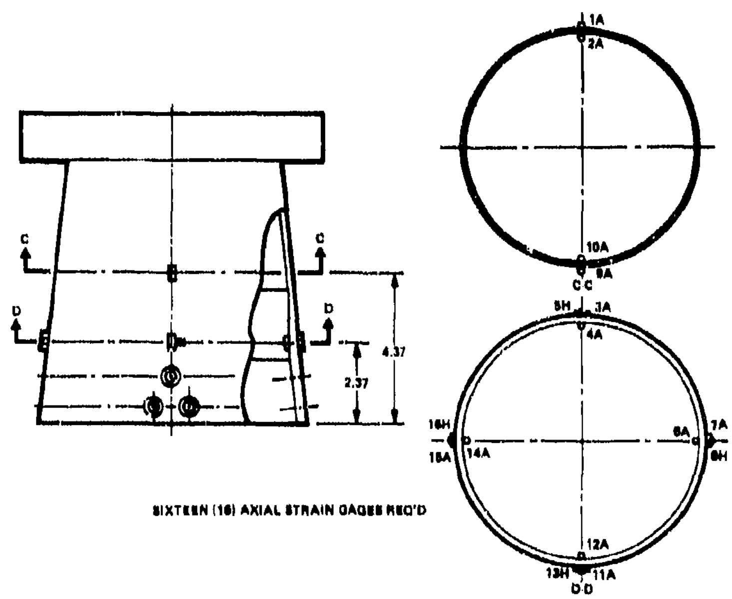


Figure 5. Strain Gage Location - Static Tests 3A and 4A

a) The test was set up as described in the foregoing section and in accordance with Figure 4.

b) Test set up was inspected by designated program personnel. Photos were taken of the set up.

c) The load, strain and DCDT were adjusted to zero reading prior to final torqueing of the 48 splice screws.

d) The splice screws were torqued to 75 in/lbs. Torqueing was done in pairs of screws diametrically opposite to minimize over stressing.

e) Strain and DCDT readings were recorded.

f) Strain and DCDT were adjusted to zero.

g) 10 percent of the Design Limit Loads were applied simultaneously and the set-up was checked for indications of mechanical interference in loading apparatus and proper operation of instrumentation. All instrumentation readings were recorded.

h) All loads were removed and all instrumentations were recorded.

i) All instrumentation was adjusted to zero at zero load.

j) Loads were applied in the following percentages of Design Limit Load until failure occurred. 20, 40, 60, 80, 100, 120, 130, 140, 150, etc. All instrumentation at each loading was recorded..

k) Failure load was recorded at 200% DLL and the shell failed on the compression side as the primary failure mode. The bolt holes were elongated but were still carrying loads.

Shear/Bending Test of Type I Joint Reinforcement Frustum
(Test 4A; Shell 04R)

1.0 TEST OBJECTIVE

The test was performed to evaluate the strucutral characteristics and load carrying capabilities of the joint reinforcement design under a single cantilevered load. This loading condition subjects the splice joints to equal tension and compression so that joint efficiency in tension and compression can be evaluated.

2.0 TEST DESCRIPTION

2.1 Hardware Configuration

The GY70/Fiberite 934 laminated frustum with joint reinforcement at the large end, part number 48126A is a section 9.1 inches long with forward and aft shell outside diameters of 5.80 inches and 7.79 inches respectively. Eleven (11) .0075 titanium shims are interleaved with thirty eight (38) GY70/Epoxy plies for reinforcement in the region of the screw holes. Two rows of 0.281 inch diameter holes with staggered pattern are used for attachment of the frustum to the test fixture with 1/4 inch countersunk screws. The two aluminum rings bonded to the shell at the small end are designed to mate with the loading fixture.

2.2 Load Condition

A load transverse to the shell axis was applied at the forward loading fixture by a 100K hydraulic jack. This loading condition subjects the splice joints to equal tension and compression on the opposite side of the neutral axis of the section. The joint efficiency in tension and compression can be evaluated from the test results.

2.3 Test Arrangement

2.3.1 Facility

The test was performed in the static test area of the Mechanical Laboratory, Martin Marietta Corporation, Orlando, Florida.

The following equipment was used to conduct the the test:

a) 100K hydraulic jack (1), Messinger
b) 100K load cell (1) BLH
c) Series 800 strain indicator (1) BLH
d) Switch and Balance Unit (1) BLH
e) Direct Current Differential Transducers (4)
f) Speed-o-max load cell indicator (1)
g) Hand pump (1) Blackhawk.

2.3.2 Mechanical Assembly

The GY70/Epoxy frustum was fastened to the test fixture at the reinforced end with forty-eight 1/4-inch diameter screws. The aluminum rings at the other end were bolted to a loading fixture with thirty-six 5/16-inch diameter bolts (150 ksi) torqued to 150 in/lbs. The assembly is cantilevered from a load reacting structural column. The 100K hydraulic jack was attached to the loading lug of the fixture at the forward end of the specimen as shown in Figure 6.

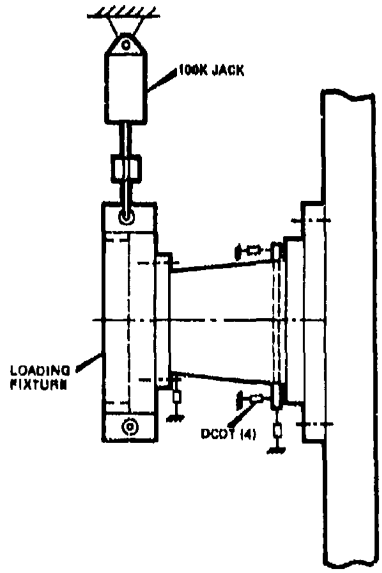


Figure 6. Test Set-Up Shear/ Bending Test - Test 4A

2.3.3 Instrumentation

2.3.3.1 Strain Measurements

A total of sixteen (16) axial type strain gages (FAE 25S-12S6) were installed on the shell specimen. Four were located in the constant thickness section of the shell to measure the maximum longitudinal shell strains. The other twelve were located in the close proximity of the splice screws to measure the local longitudinal and hoop strains. The locations of all the strain gages are shown in Figure 5.

2.3.3.2 Deflection Measurements

One DCDT located at the cantilevered end of the shell specimen was used to measure the deflection of the free end under load. The other

three DCDT's were used to measure the test fixture deflections at the fixed end of the specimen can be obtained from the measurements. The location of the DCDT's are shown in Figure 6.

Test Procedure

The GY70/Epoxy frustum shear/bending test was conducted as follows:

a) The test was set up as described in the foregoing section and in accordance with Figure 6.

b) The test set up was inspected by designated program personnel and photos were taken.

c) The load, strain and DCDT were adjusted to zero reading prior to final torqueing of the 48 splice screws.

d) The splice screws were torqued to 75 in/lbs. Torqueing was done in pairs of screws diametrically opposite to minimize over stressing.

e) Strain and DCDT readings were recorded.

f) Strain and DCDT were adjusted to zero.

g) 2,000 lbs. preload was applied and the set up and instrumentation readings were checked.

h) The load was removed all instrumentation was recorded.

i) All instrumentation was adjusted to zero at zero load.

j) Load was applied in the following increments:

2,000 lbs. increments to 20,000 lbs.
1,000 lbs. increments above 20,000 lbs.

All instrumentation at each load increment was recorded.

k) Failure load was recorded at 34,000 lbs. The shell fractured at the small end. The bolt holes were elongated but were still capable of sustaining loads.

APPENDIX F

SHOCK SPECTRA FROM SHOCK TESTS

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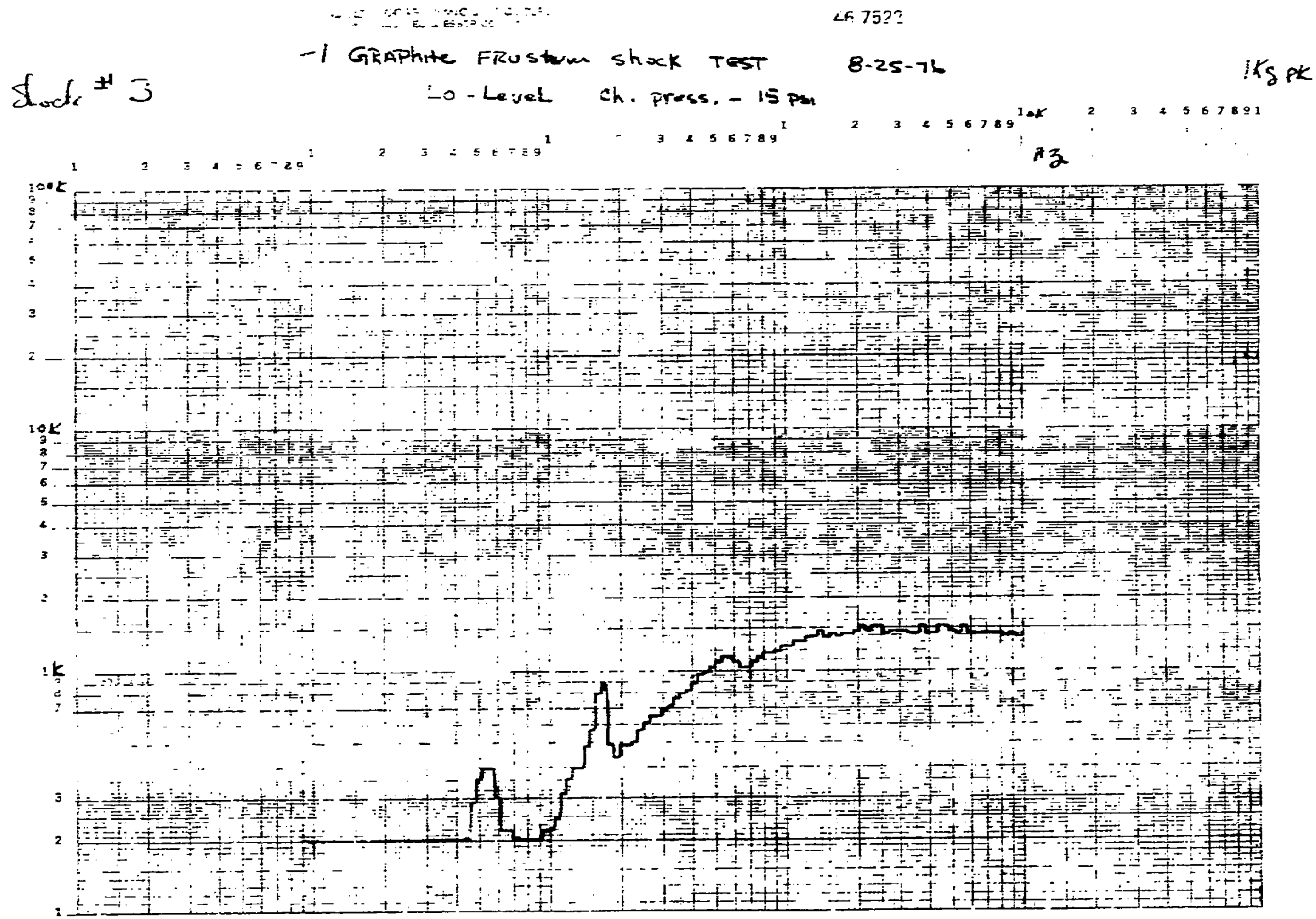

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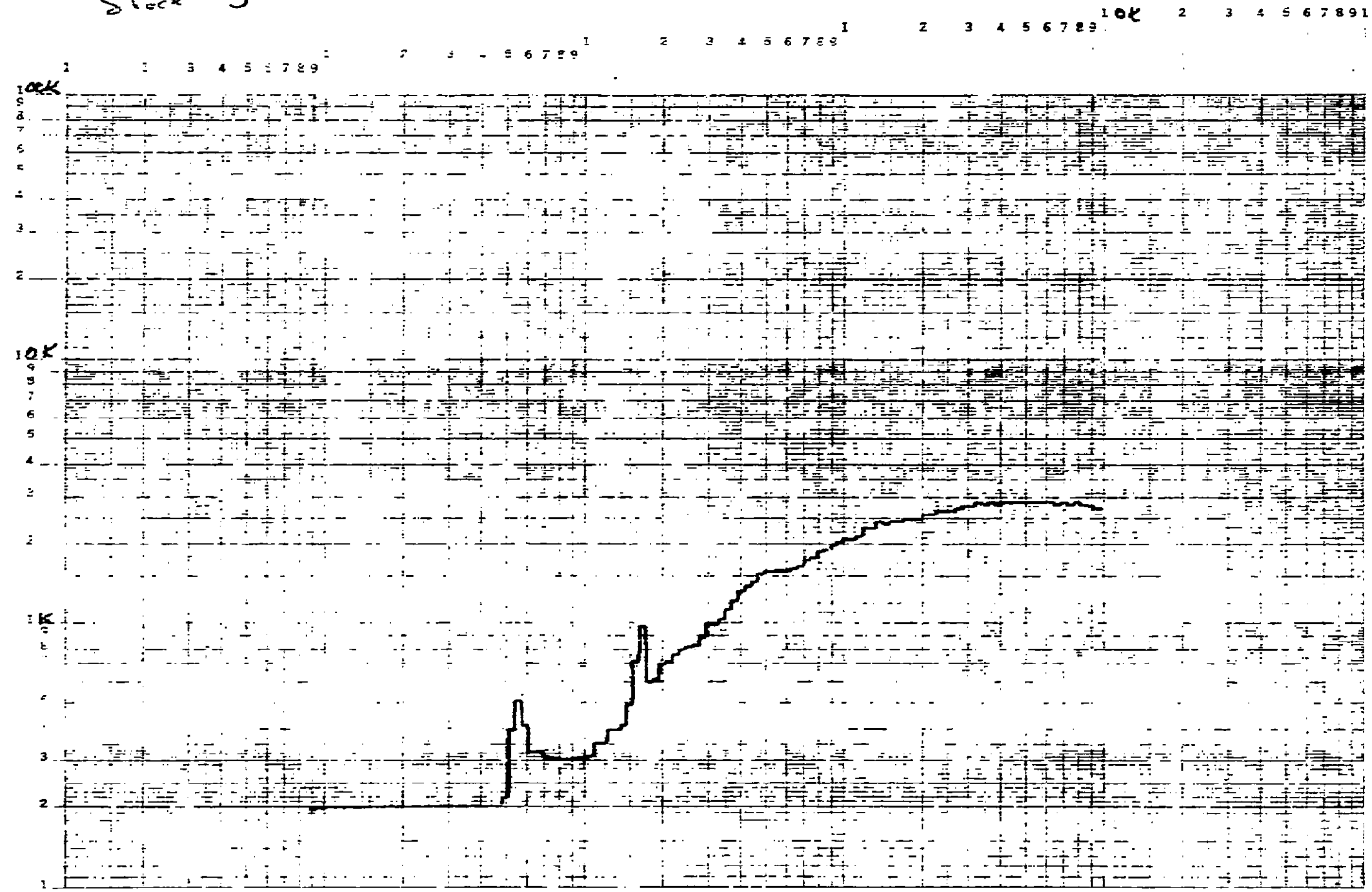
46 7522

-1 Graphite Frostrum shock test 8-25-76

Lo-Level - Ch. Press - 20 psi

2 Kg PK

Shock # 5



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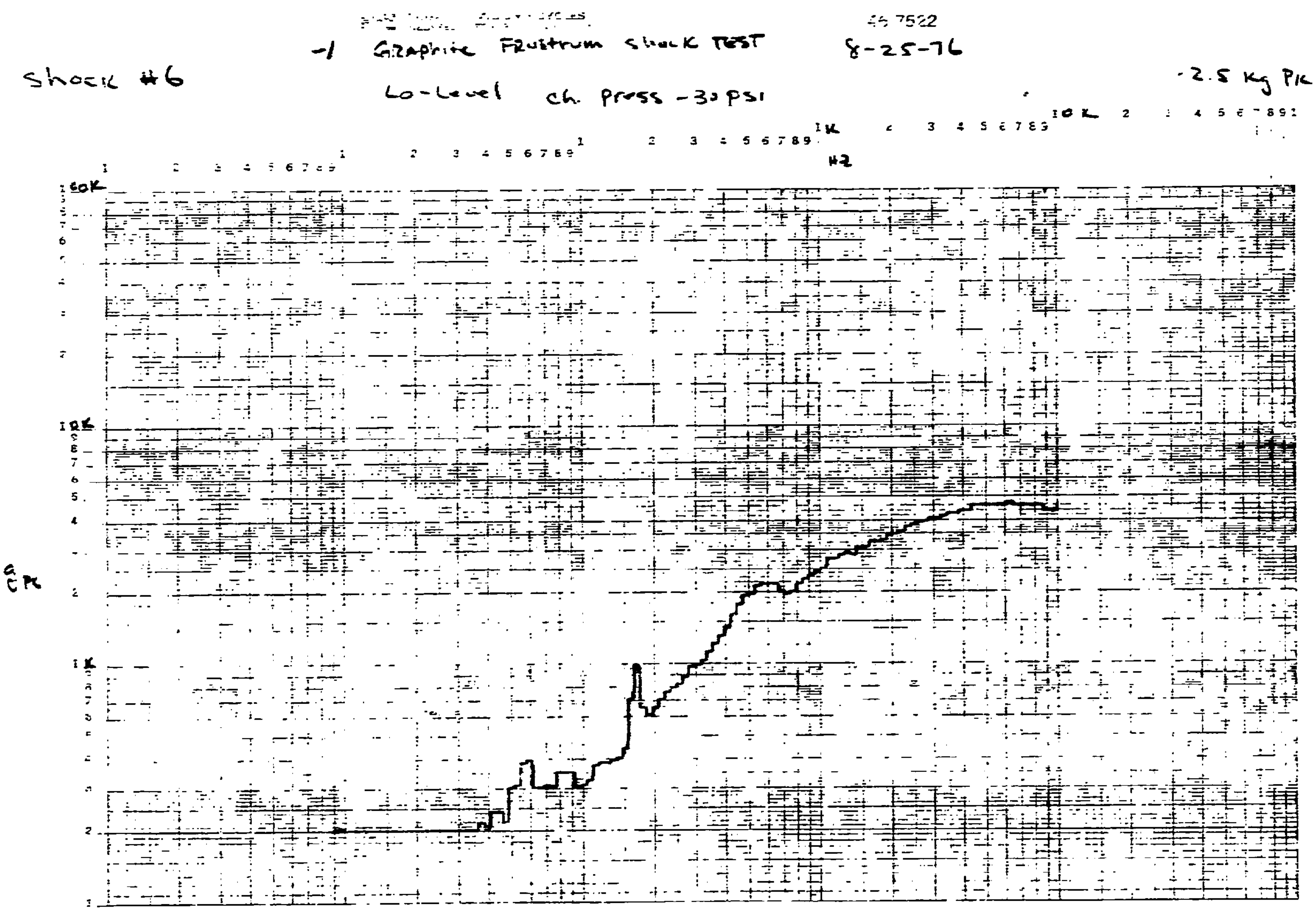

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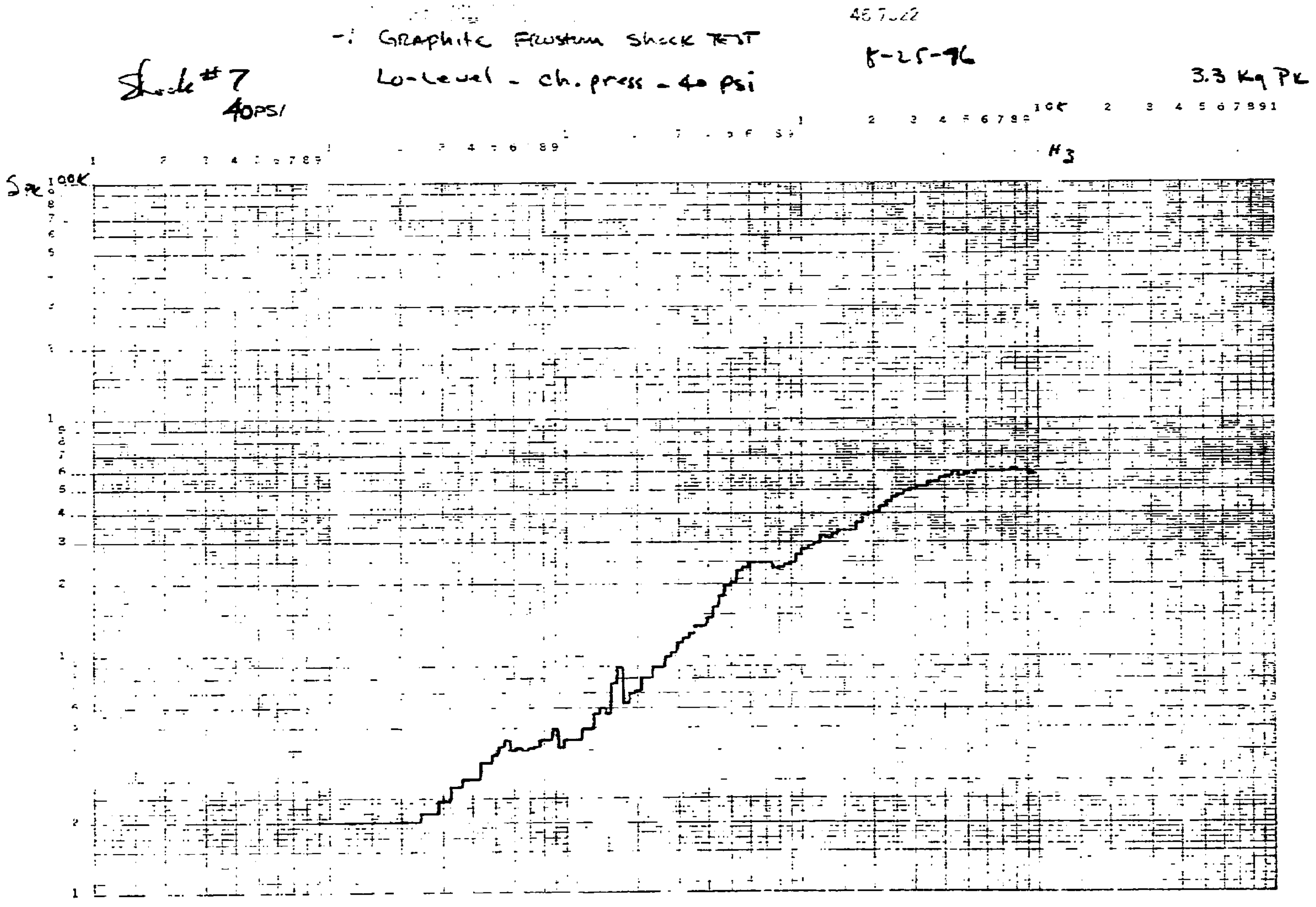

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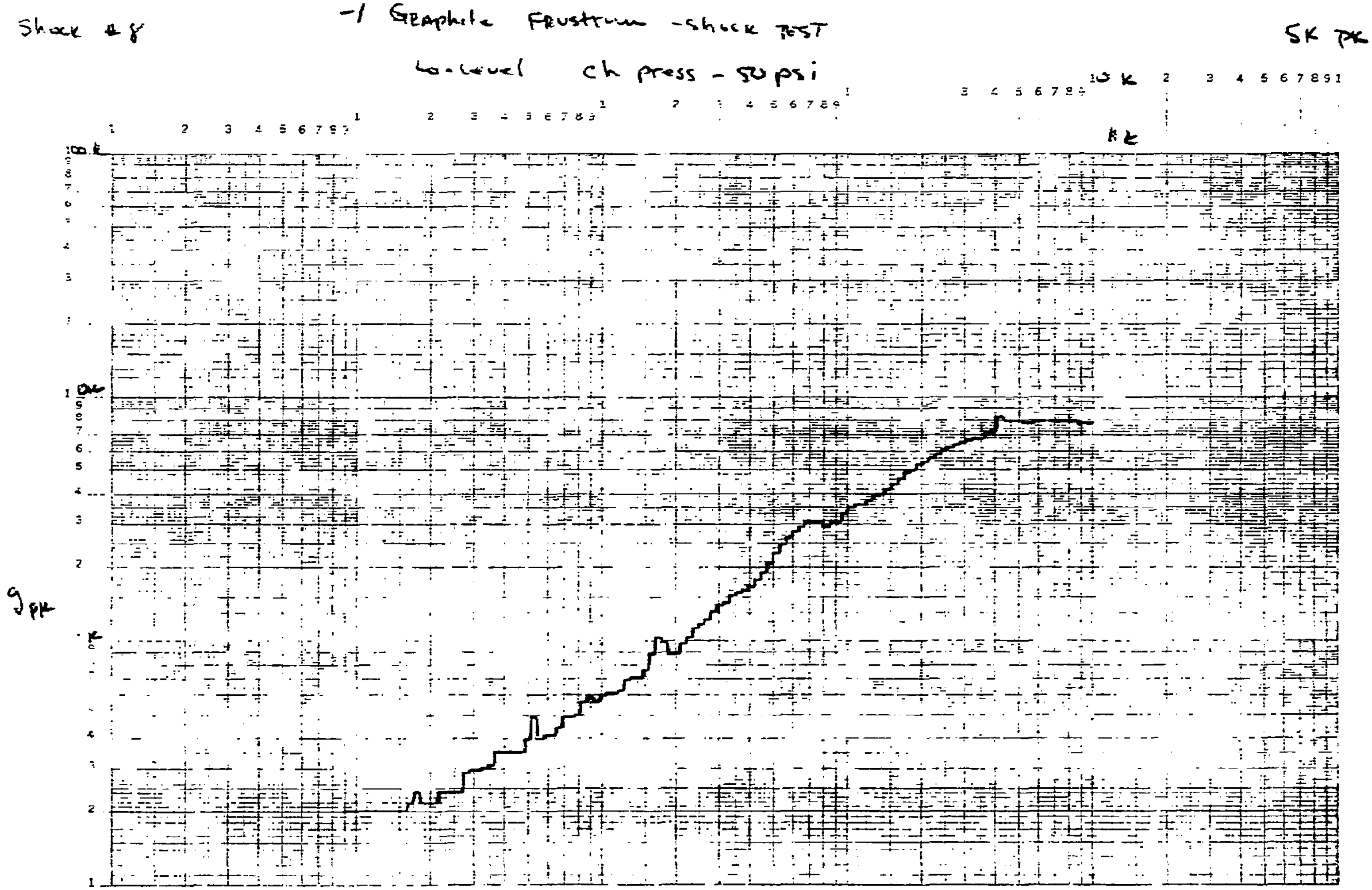

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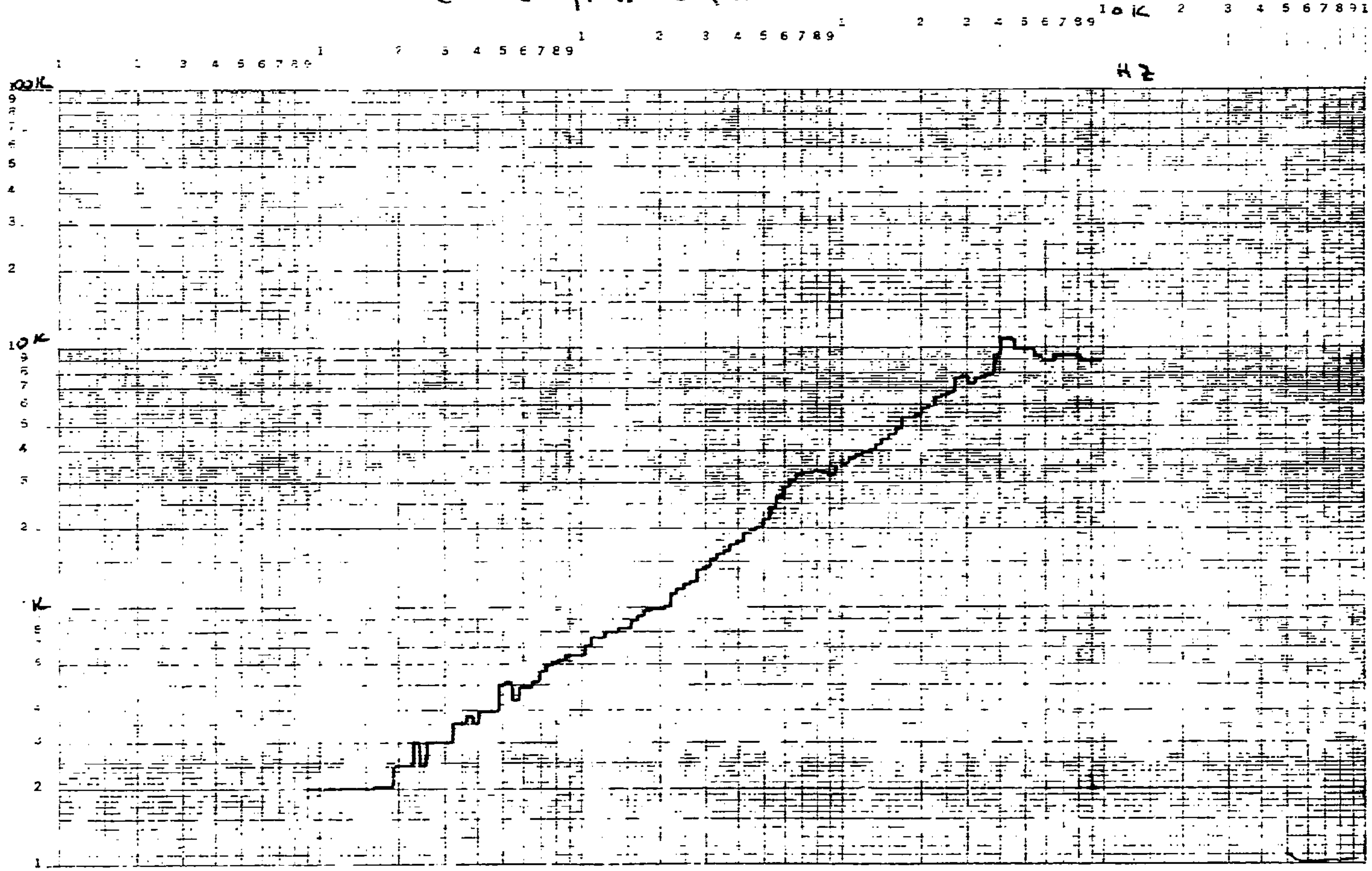
46 7322

-1 Graphite Frustum - Shock Test

Shock #9

Lo - Level   Ch. press - 60psi

5.5 K pk



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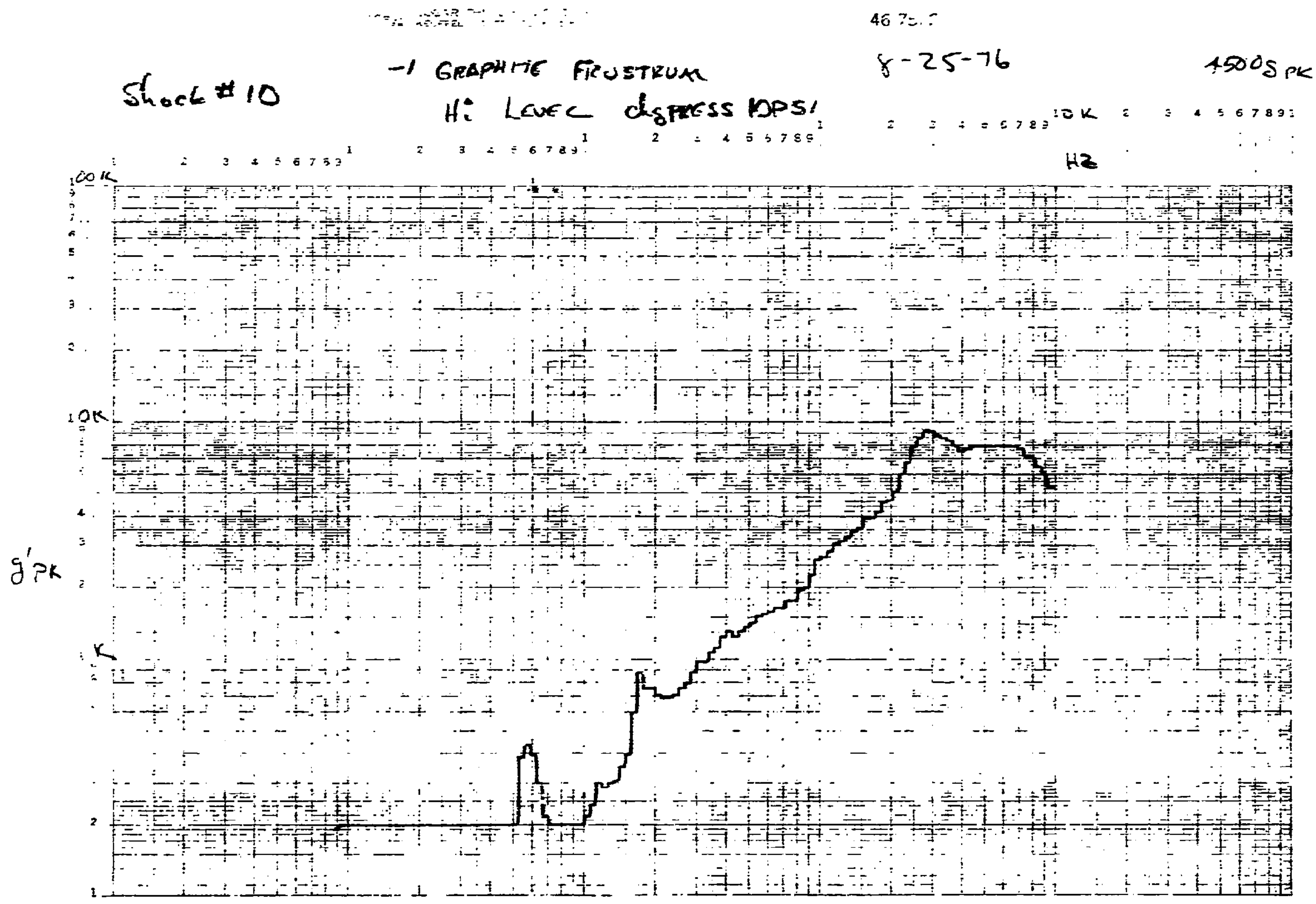

46 75
Shock #10
-1 GRAPHITE FRUSTRUM
Hi LEVEL
8-25-76
4500 S PK
10K
Hz
100K
10K
K
g' PK

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-67572

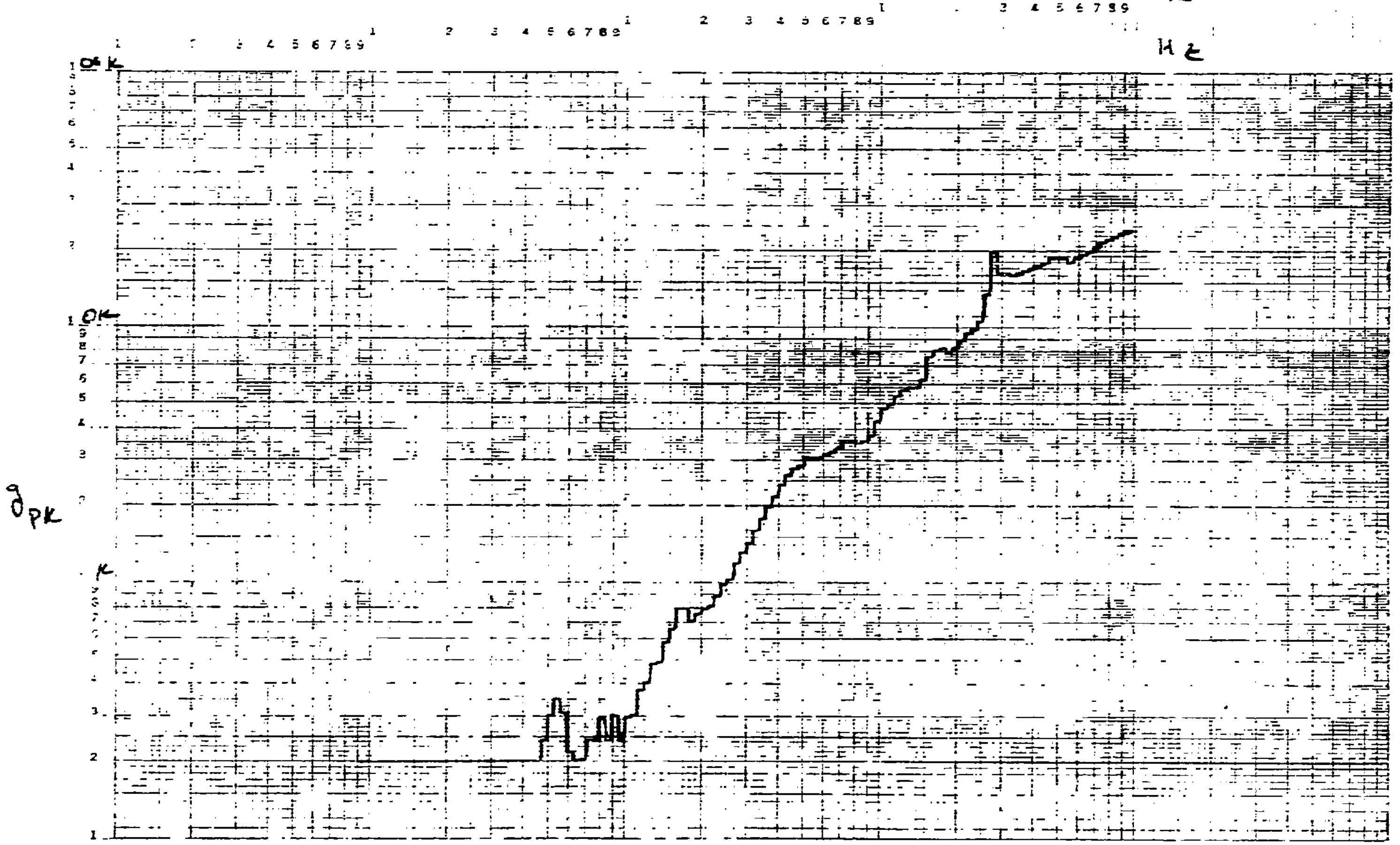
Shock TEST #11

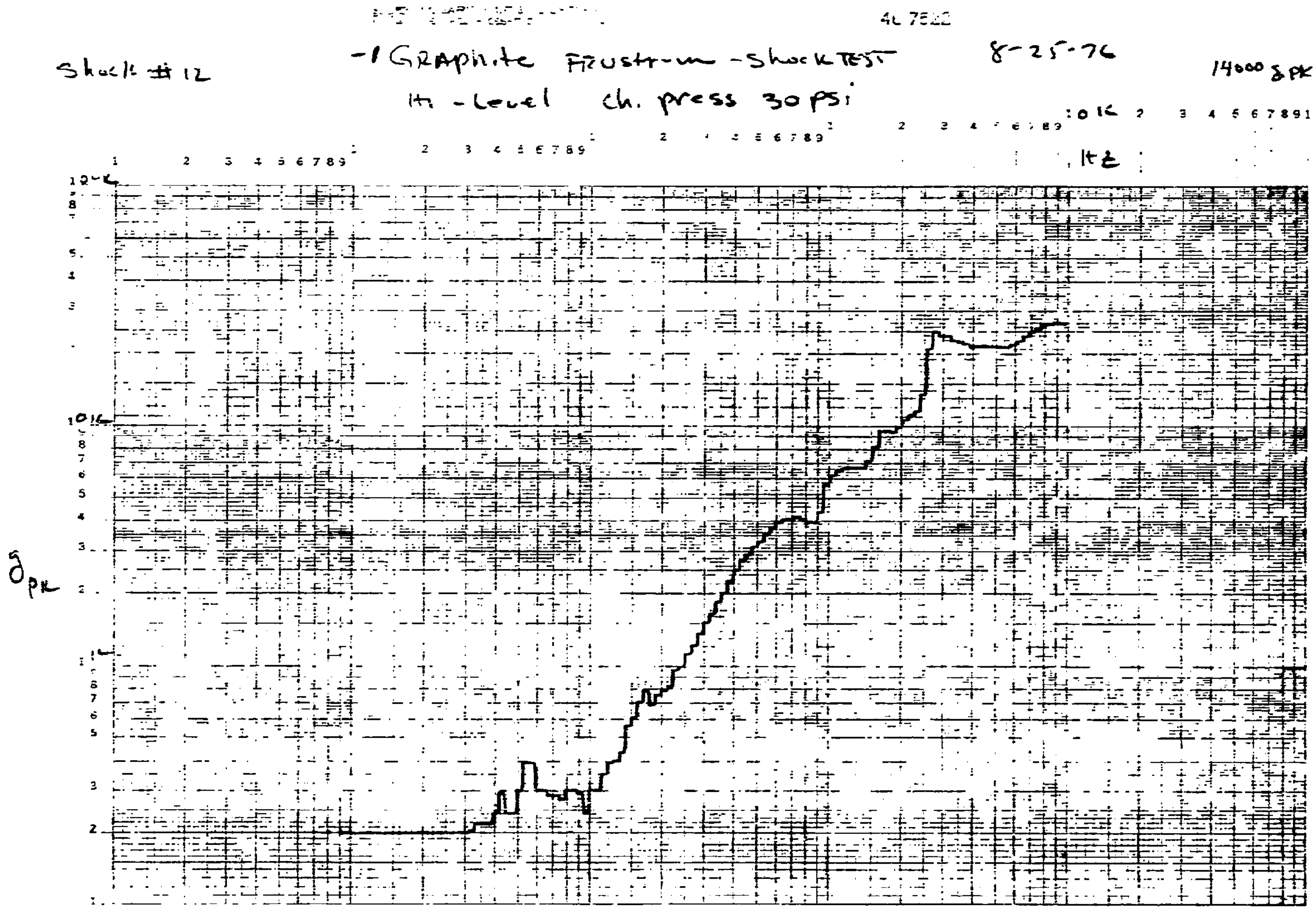
-1 Graphite Frustrum - shock TEST

Hi - Level ch - pressure - 20 psi

8-25-76

11,000 g pk




4L 7522
Shock #12
-1 Graphite Frustrum - Shock Test
8-25-76
14000 g pk
Hi-Level ch. press 30 psi
Hz
δ_{pk}
10K
1K

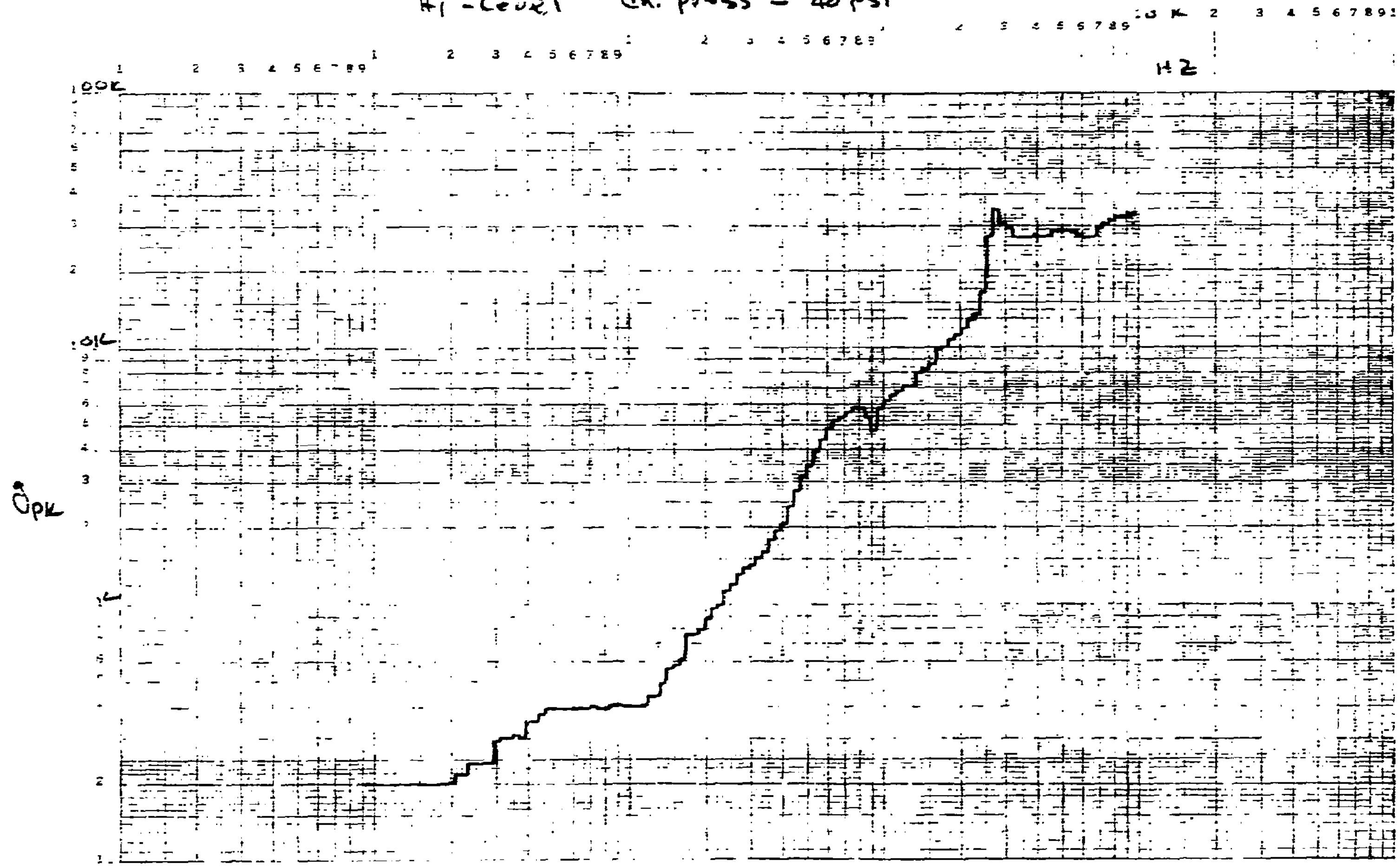
46.32

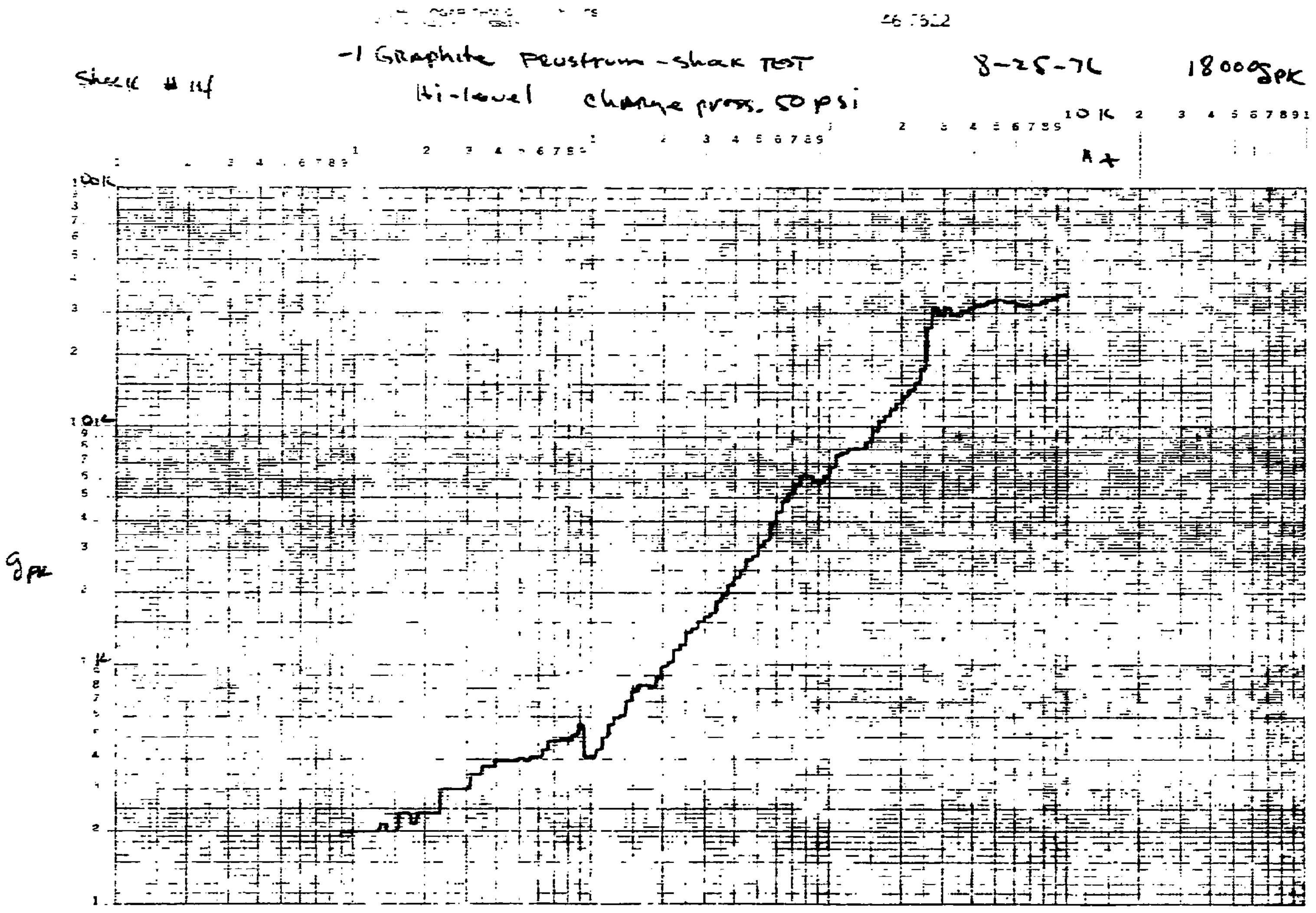
Shock # 13

-1 Graphite Frustrum - Shock TEST

Hi-Level ch. press - 40 psi

16 500 gpk




46 7522
-1 Graphite Frustrum - shock TEST
8-25-76
18000 gpk
Sheet # 14
Hi-level charge press. 50 psi
10 K
100K
10K
1K
gpk
Hz

BEST AVAILABLE COPY

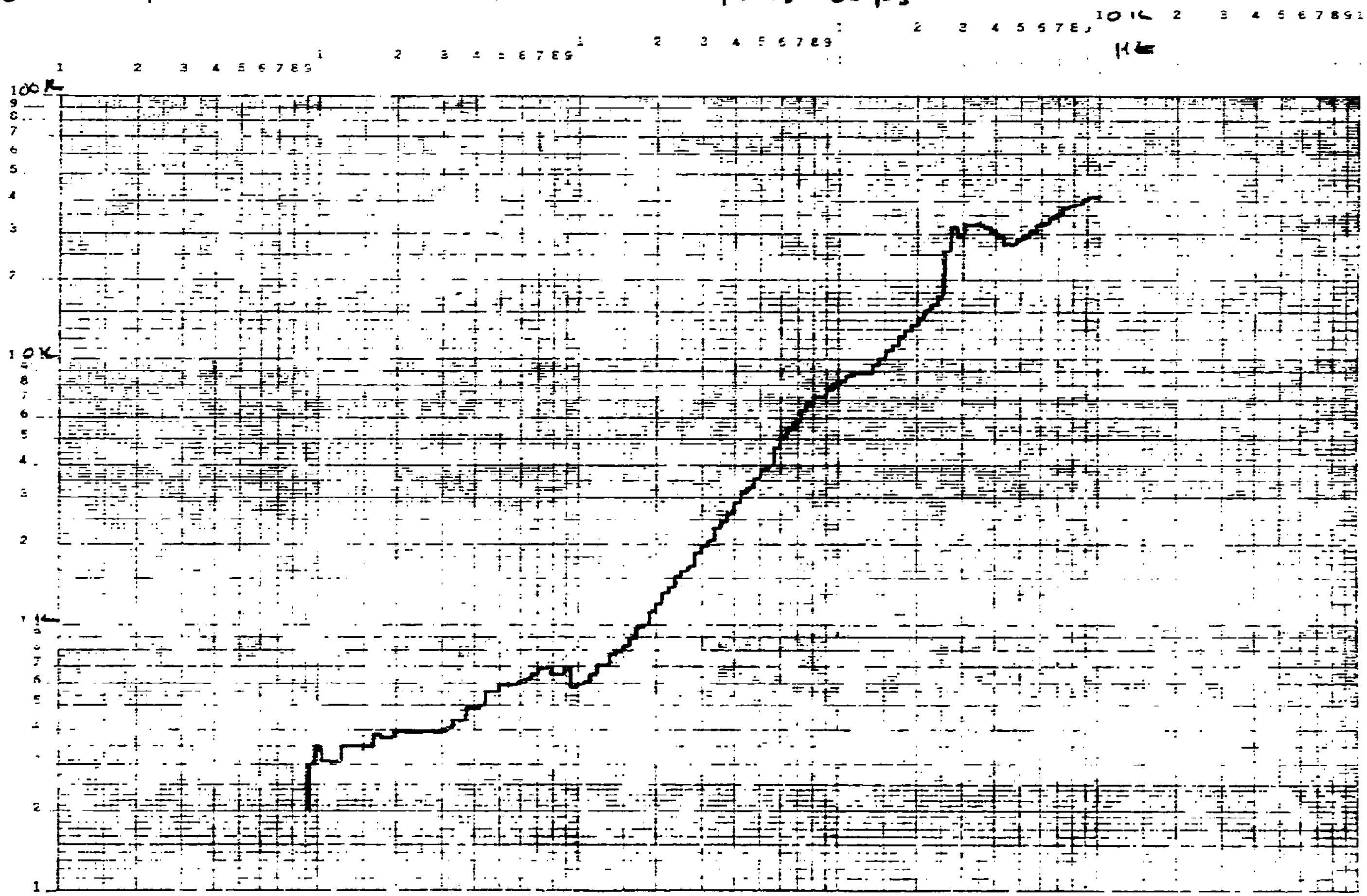
45 7522

-1 Graphite Frustrum - shock Test

Shock # 15

Hi - Level ch. press - 60 psi

19000 gpk



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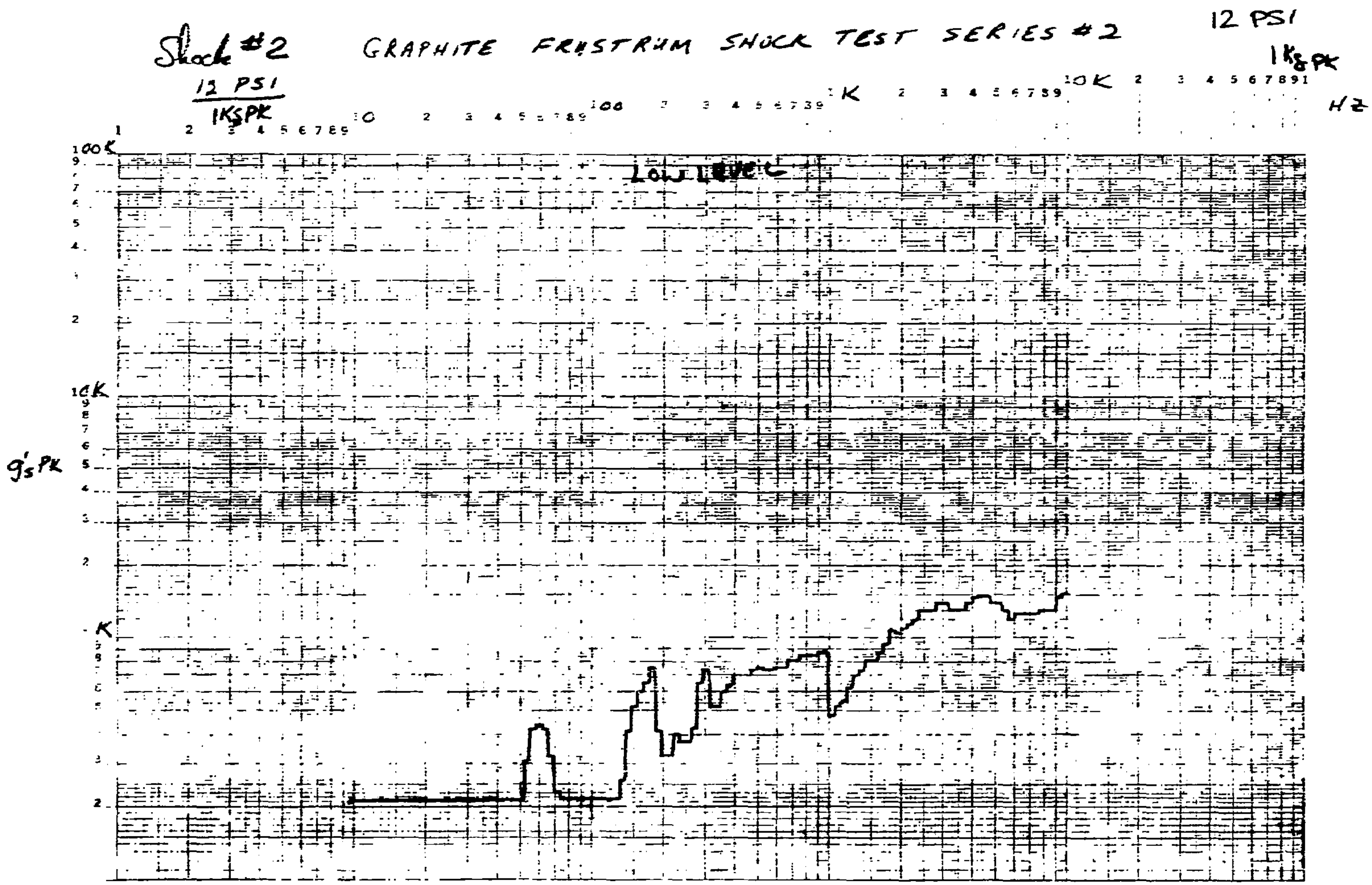
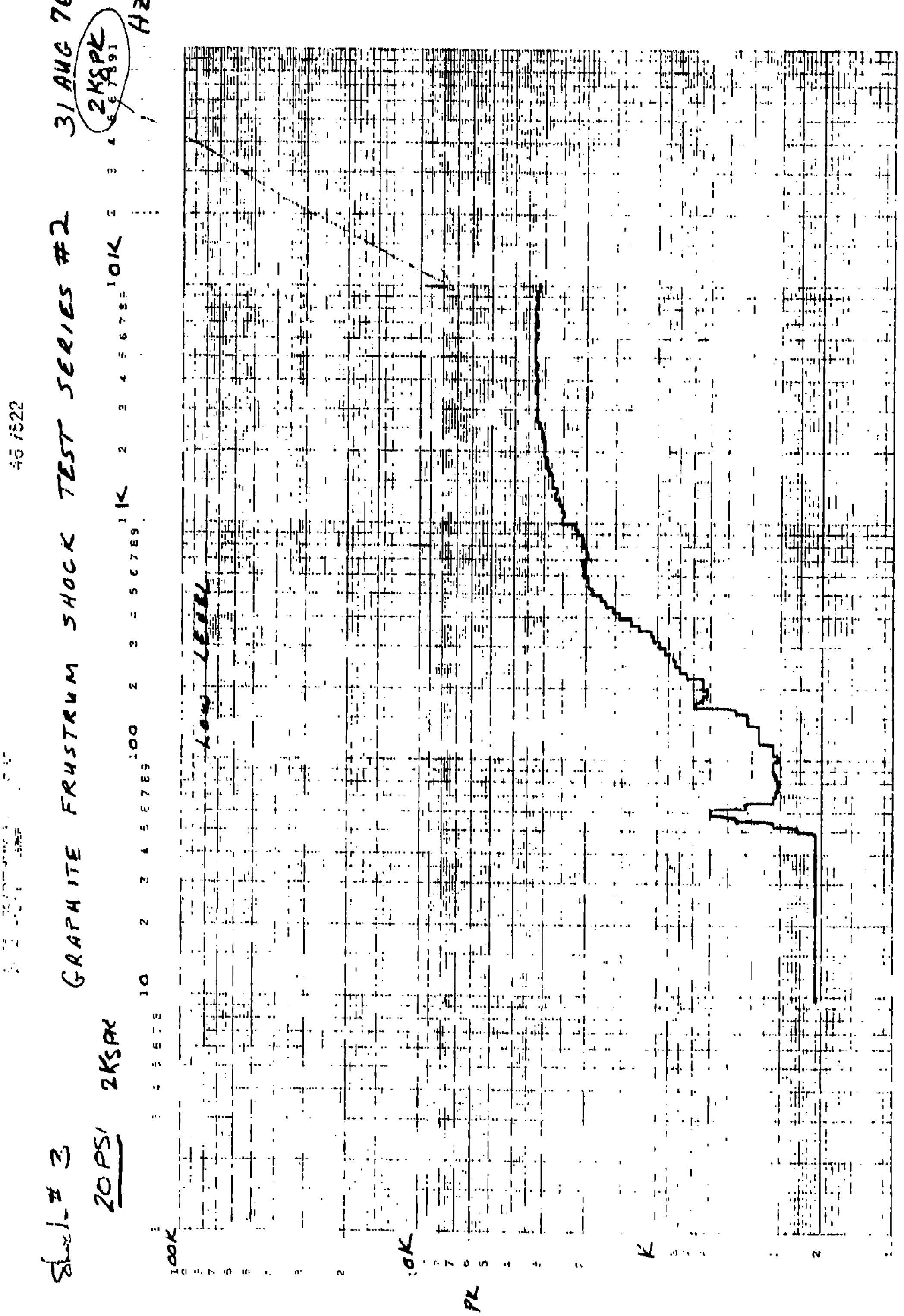
46 7522





Shock # 3
20 PSI
2KSPK
GRAPHITE FRUSTRUM SHOCK TEST SERIES #2
31 AUG 76
2KSPK
Hz
46 1522
LOW LEVEL
10
100
1K
10K
100K
10K
K
g's PK

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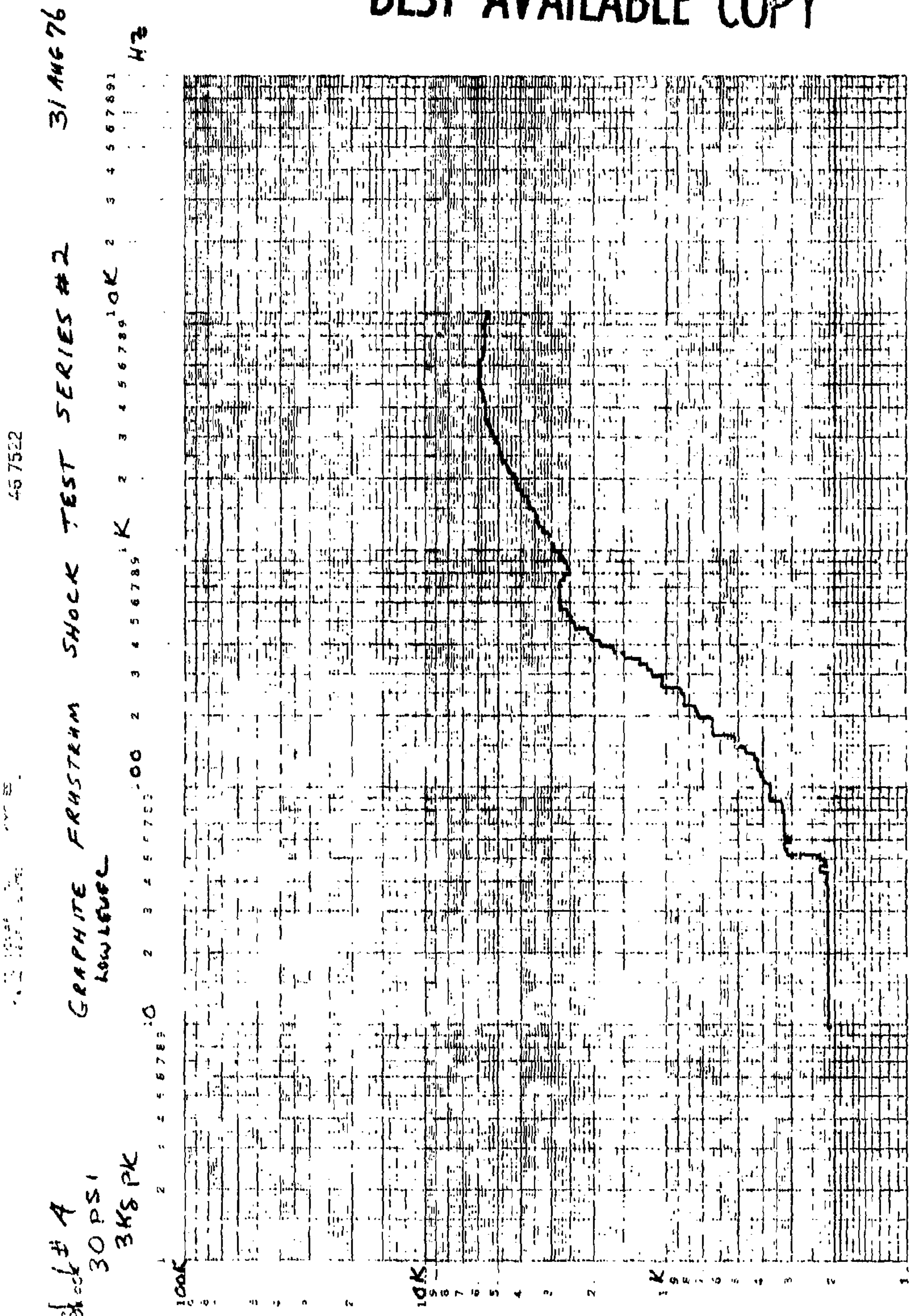
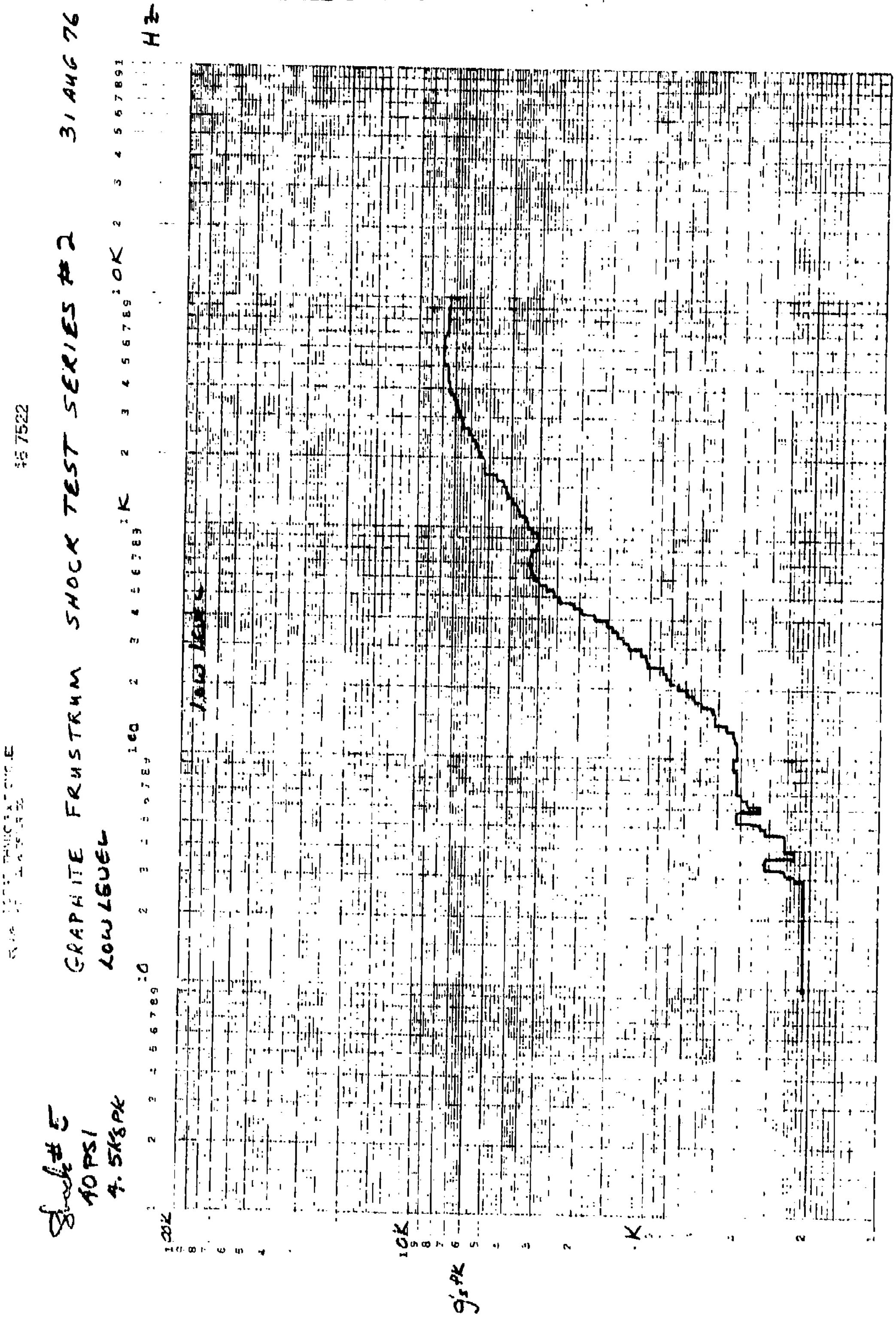
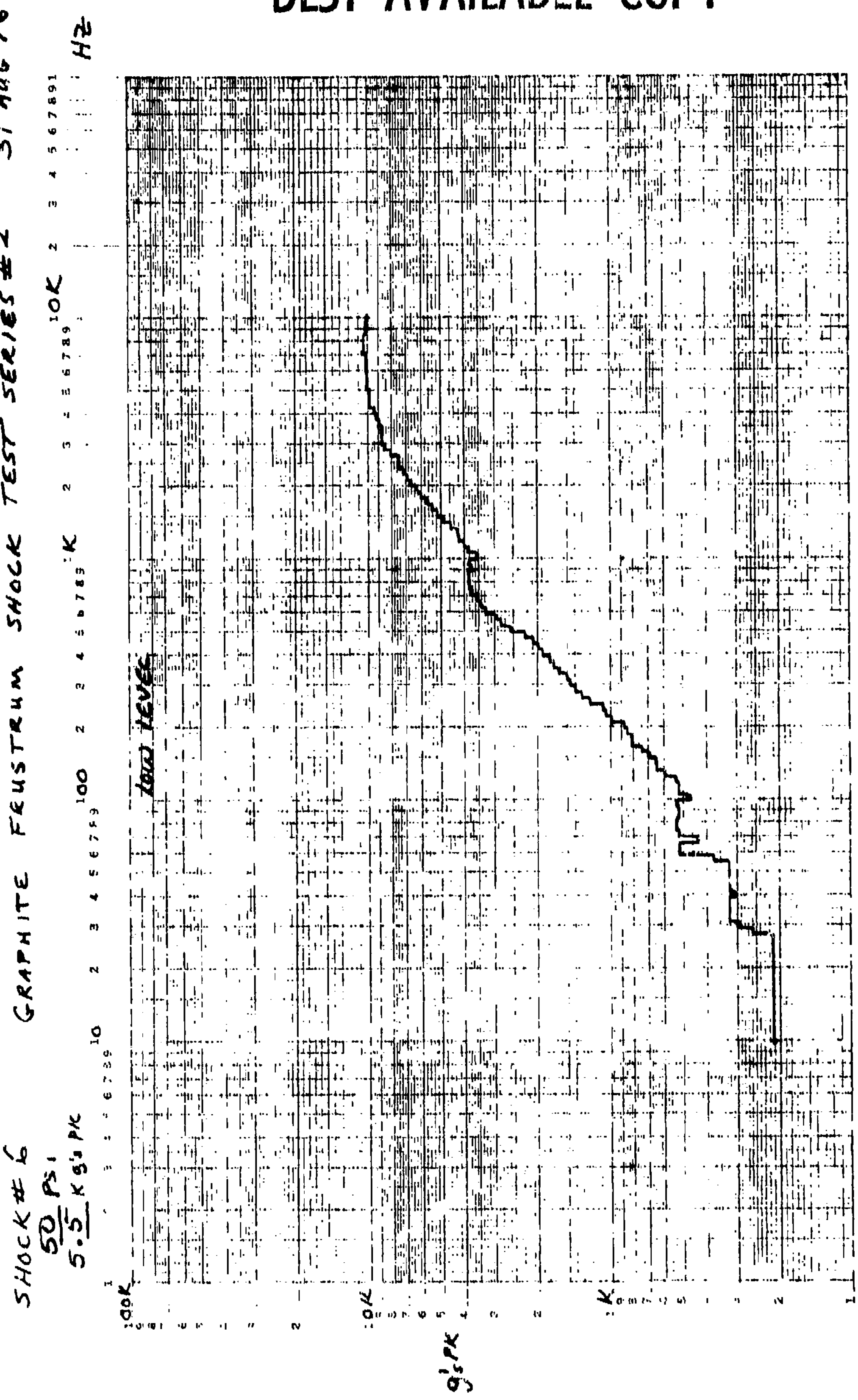



GRAPHITE FRUSTRUM SHOCK TEST SERIES #2
31 AUG 76
LOW LEVEL
40 PSI
4. 5K g PK
Hz
g's PK
10K
1K
100
10

BEST AVAILABLE COPY

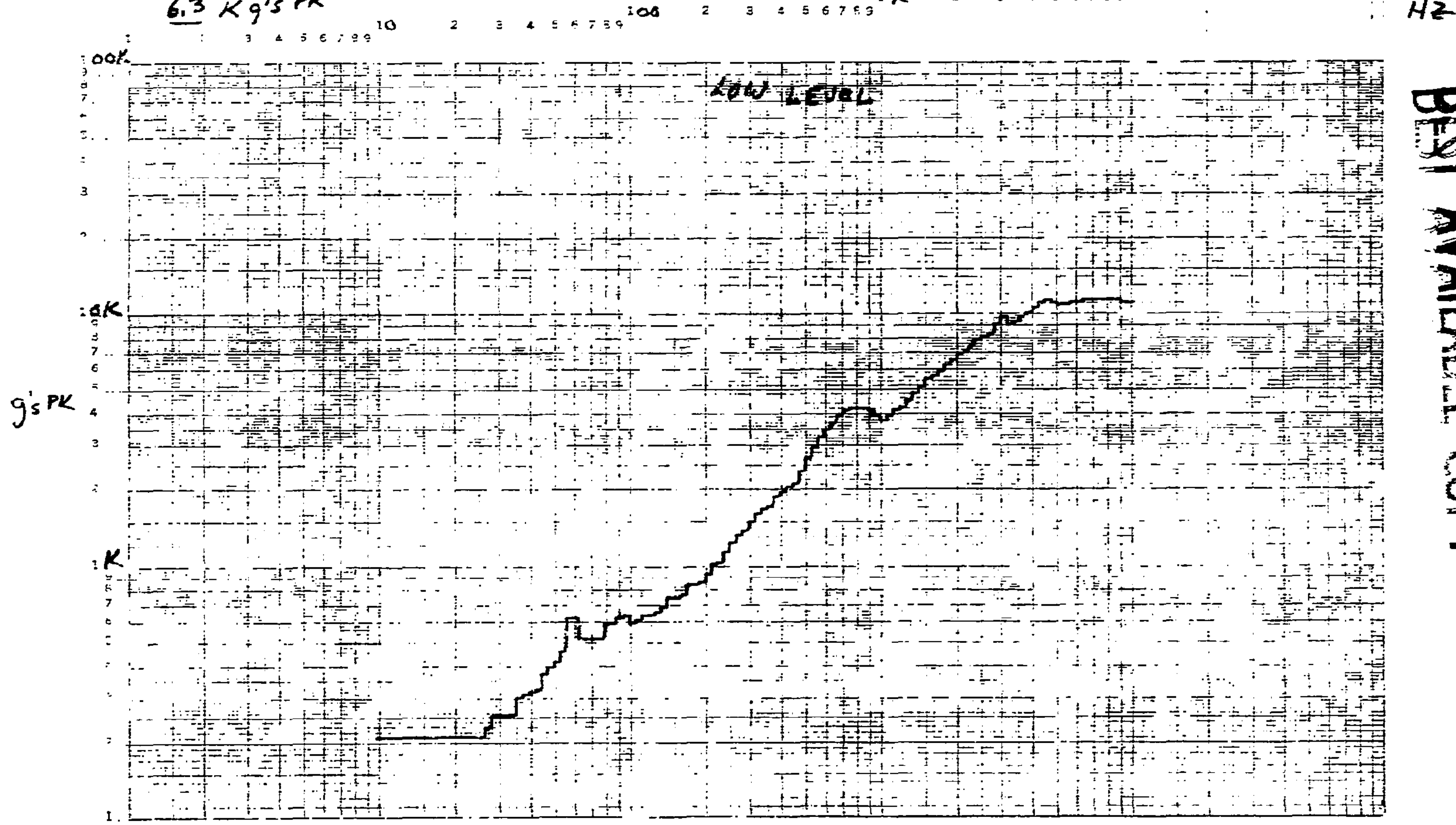


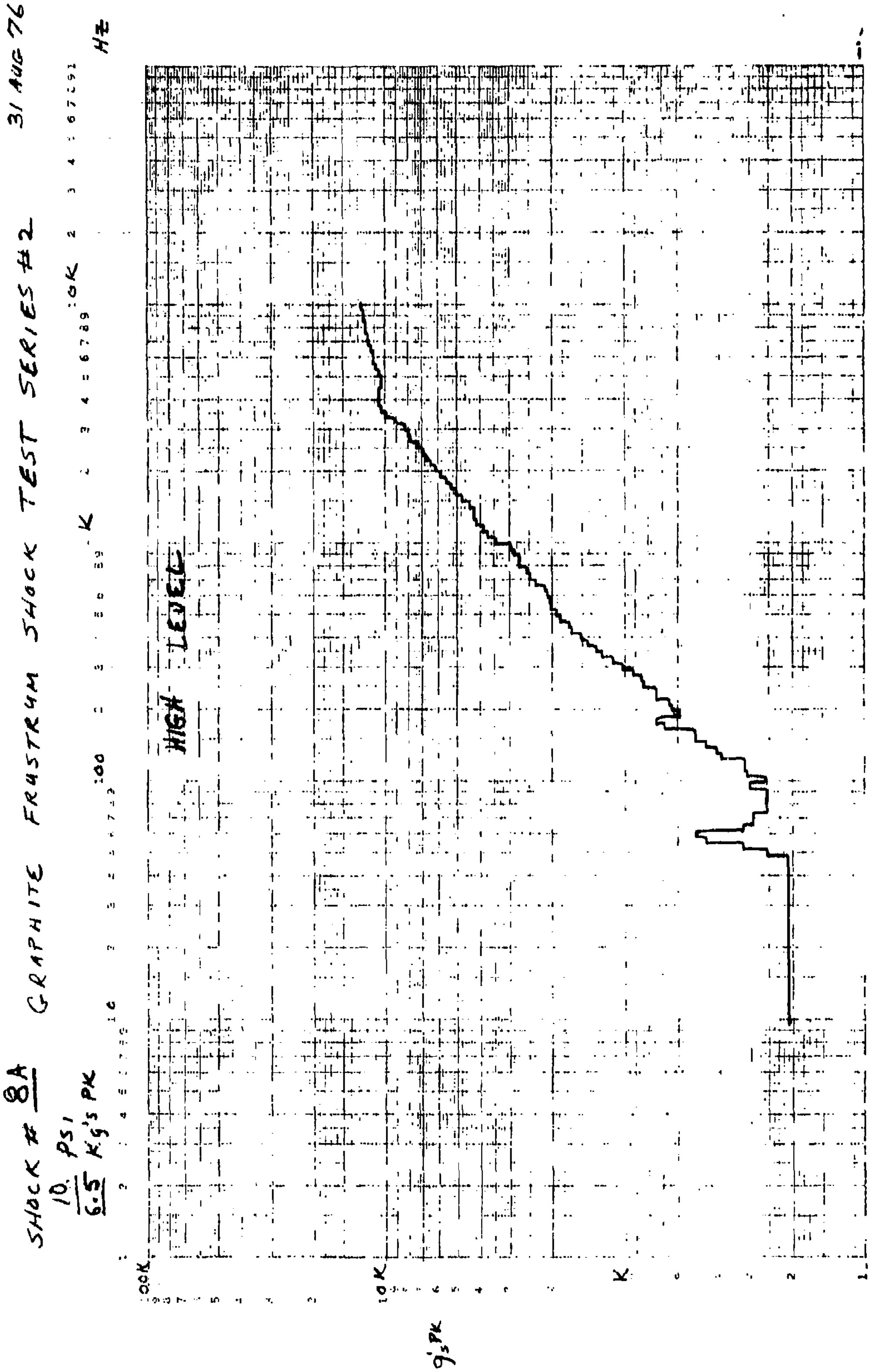
46 7522

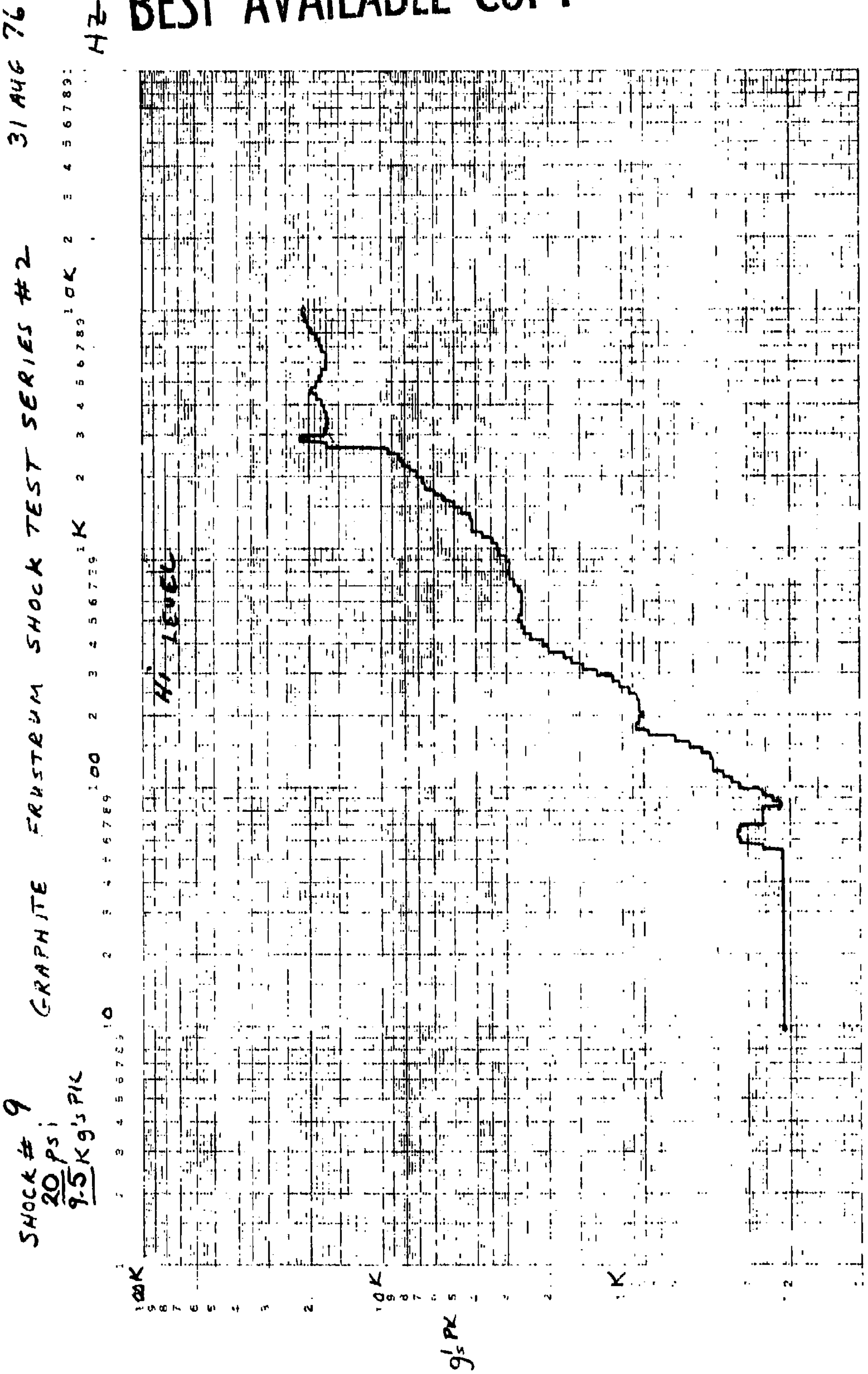
SHOCK # 7 GRAPHITE FRUSTRUM SHOCK TEST SERIES #2 31 AUG 76

60 Psi

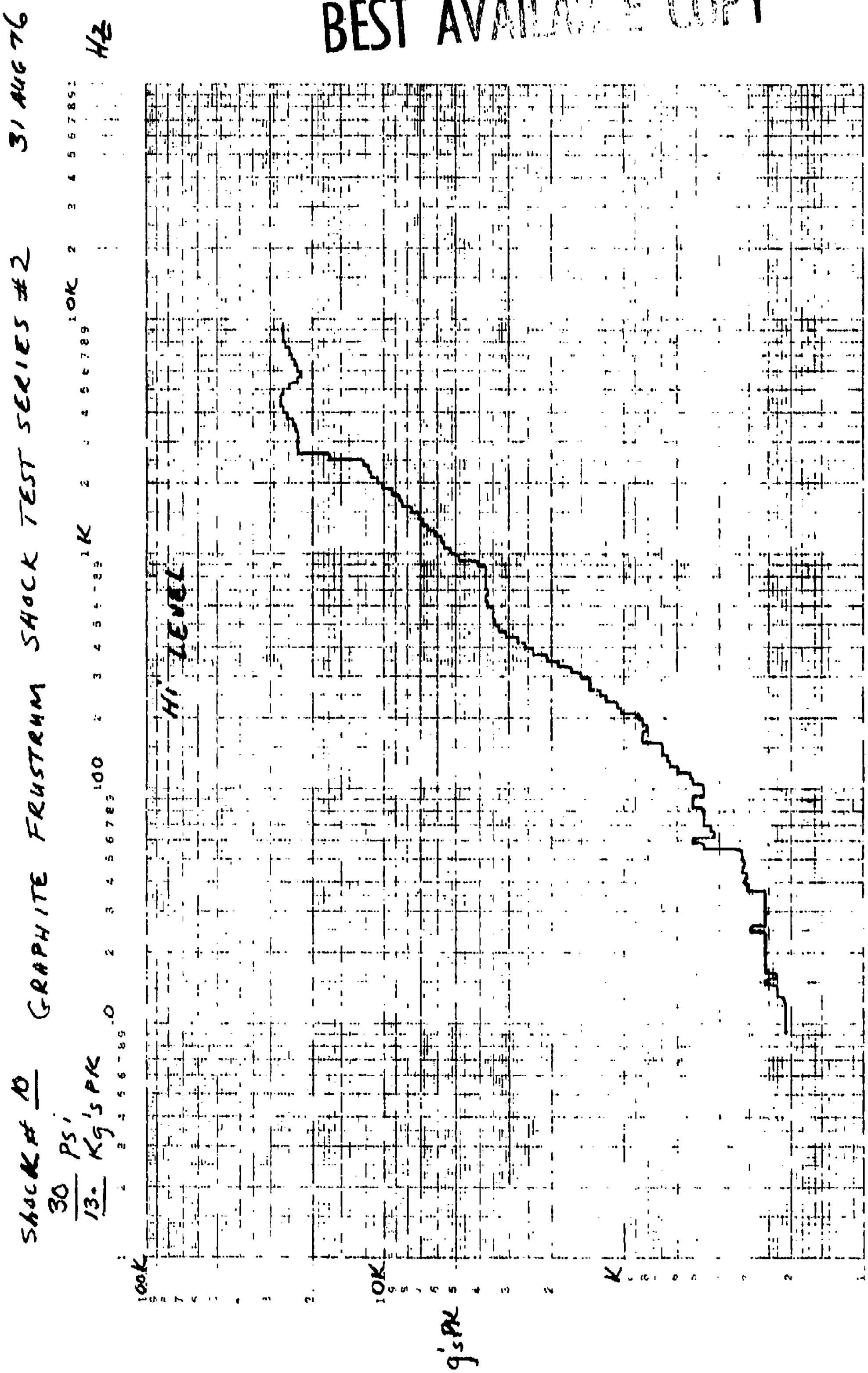
6.3 K g's PK




SHOCK # 8A
10. PSI
6.5 K g's PK
GRAPHITE FRUSTRUM SHOCK TEST SERIES #2
31 AUG 76
HIGH LEVEL
Hz
g's PK


SHOCK # 9
20 PSI
9.5 K g's PK
GRAPHITE FRUSTRUM SHOCK TEST SERIES #2
31 AUG 76
Hz
HI LEVEL
10
100
1K
10K
100K
g's PK

BEST AVAILABLE COPY



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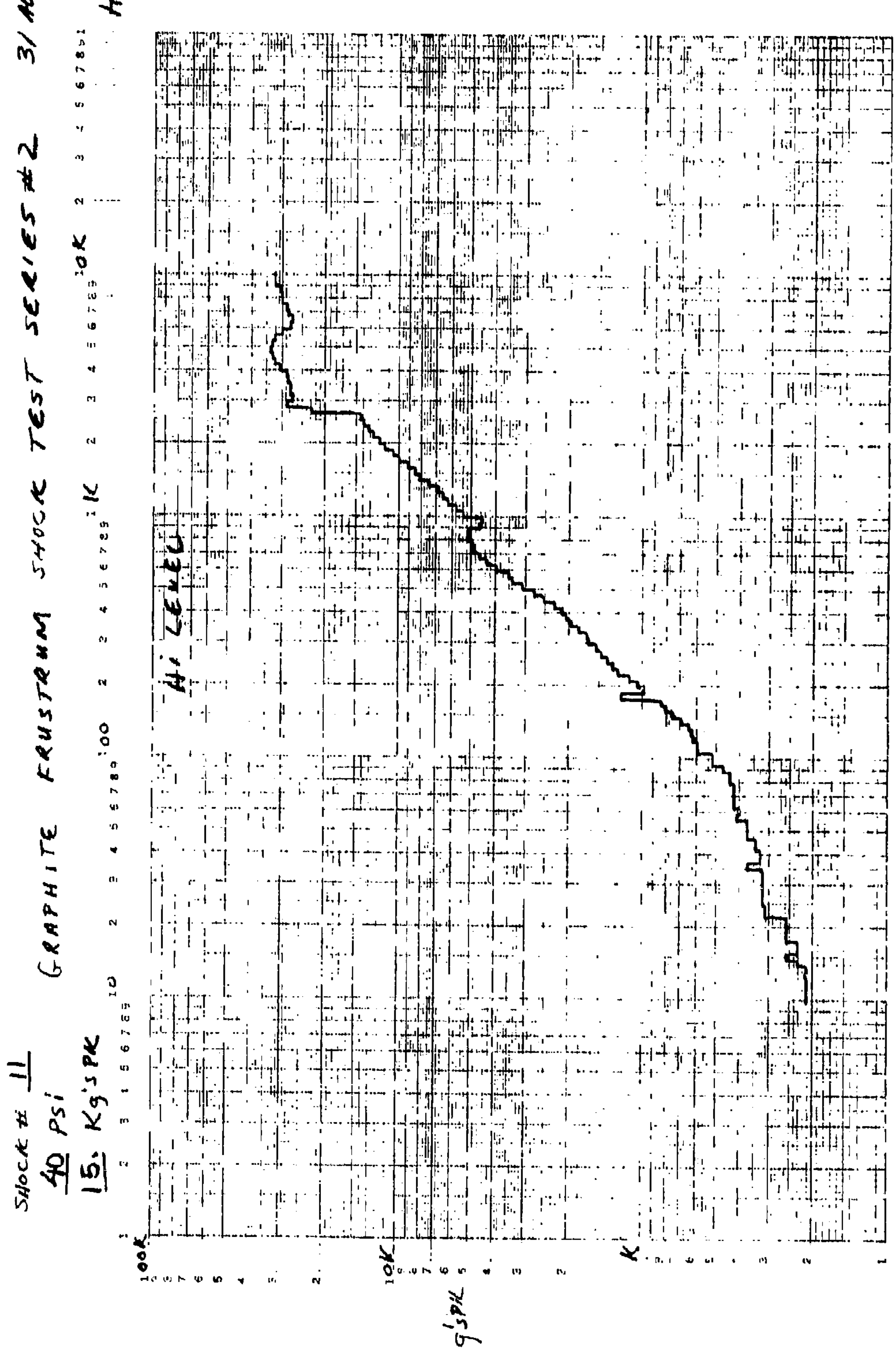


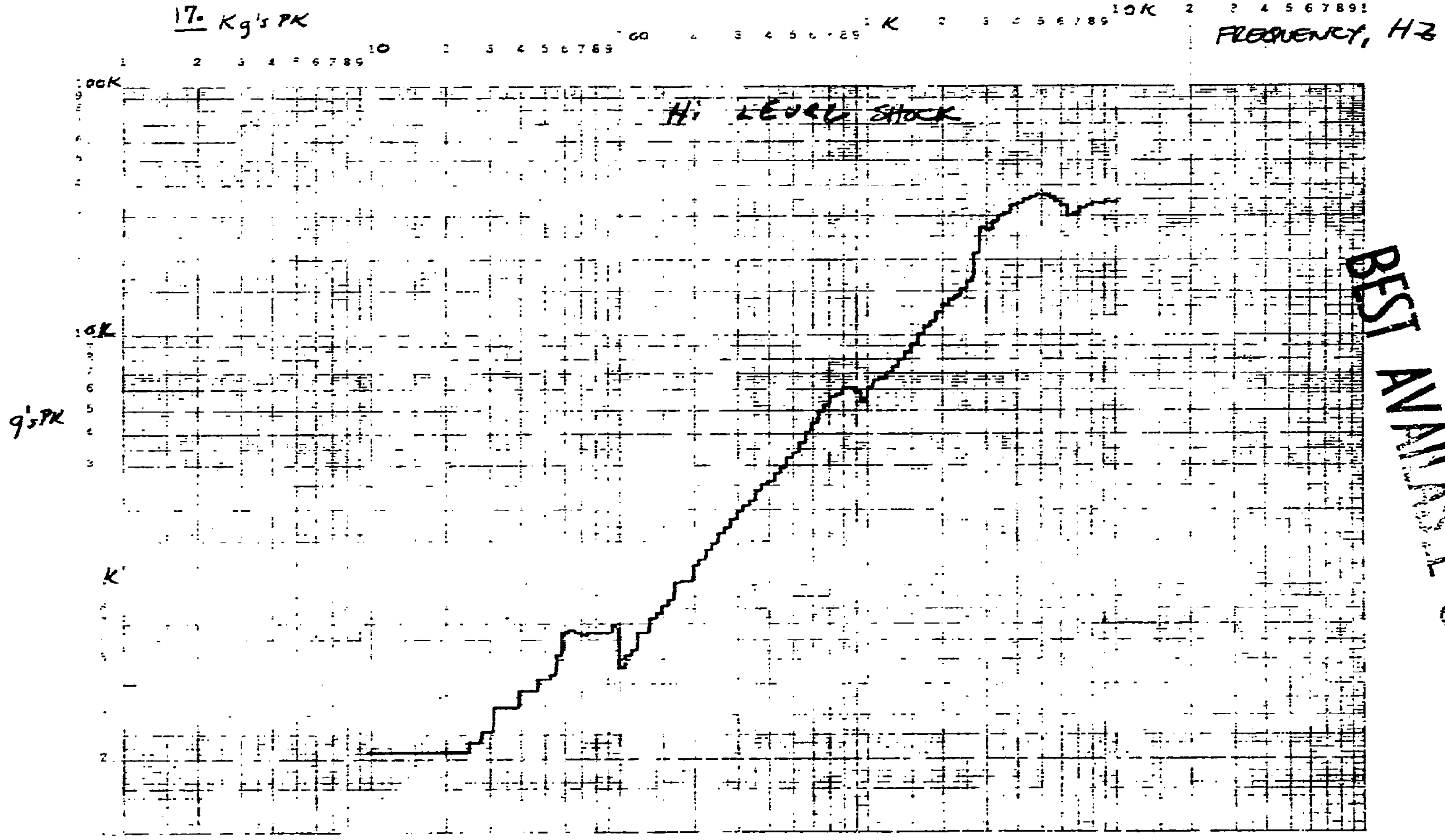
SHOCK # 12

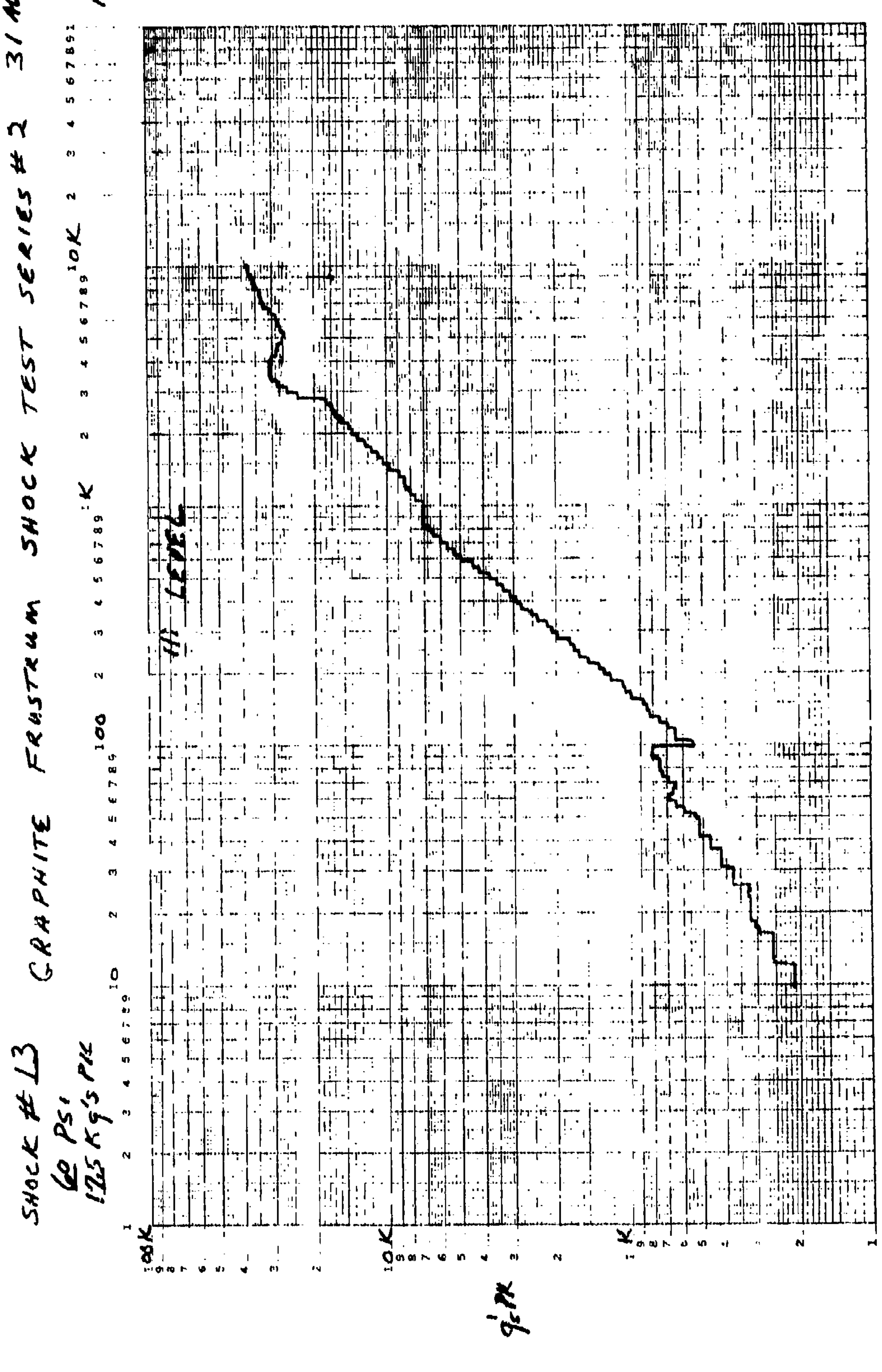
50 psi

17. Kg's PK

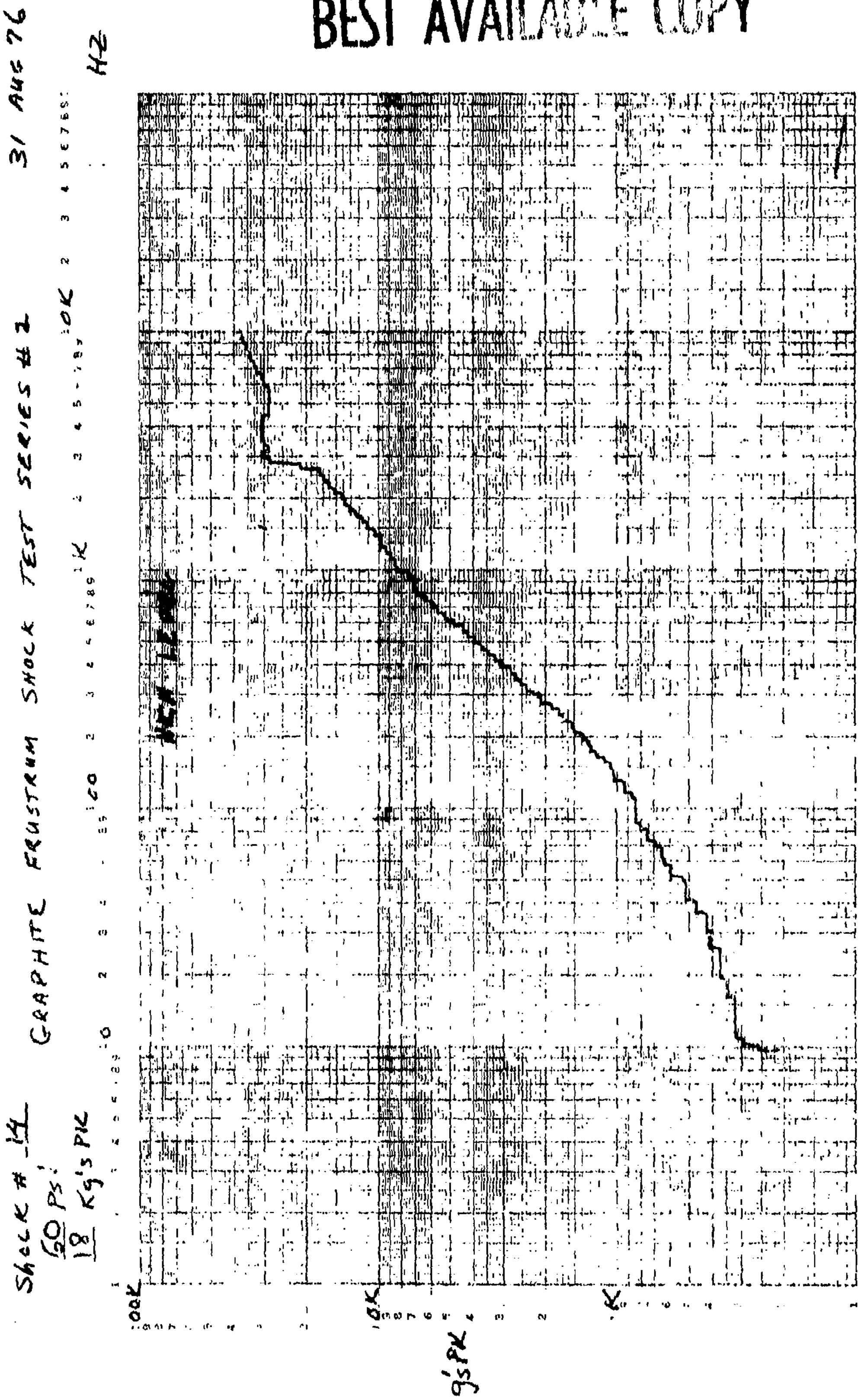
GRAPHITE FRUSTRUM SHOCK TEST SERIES #2

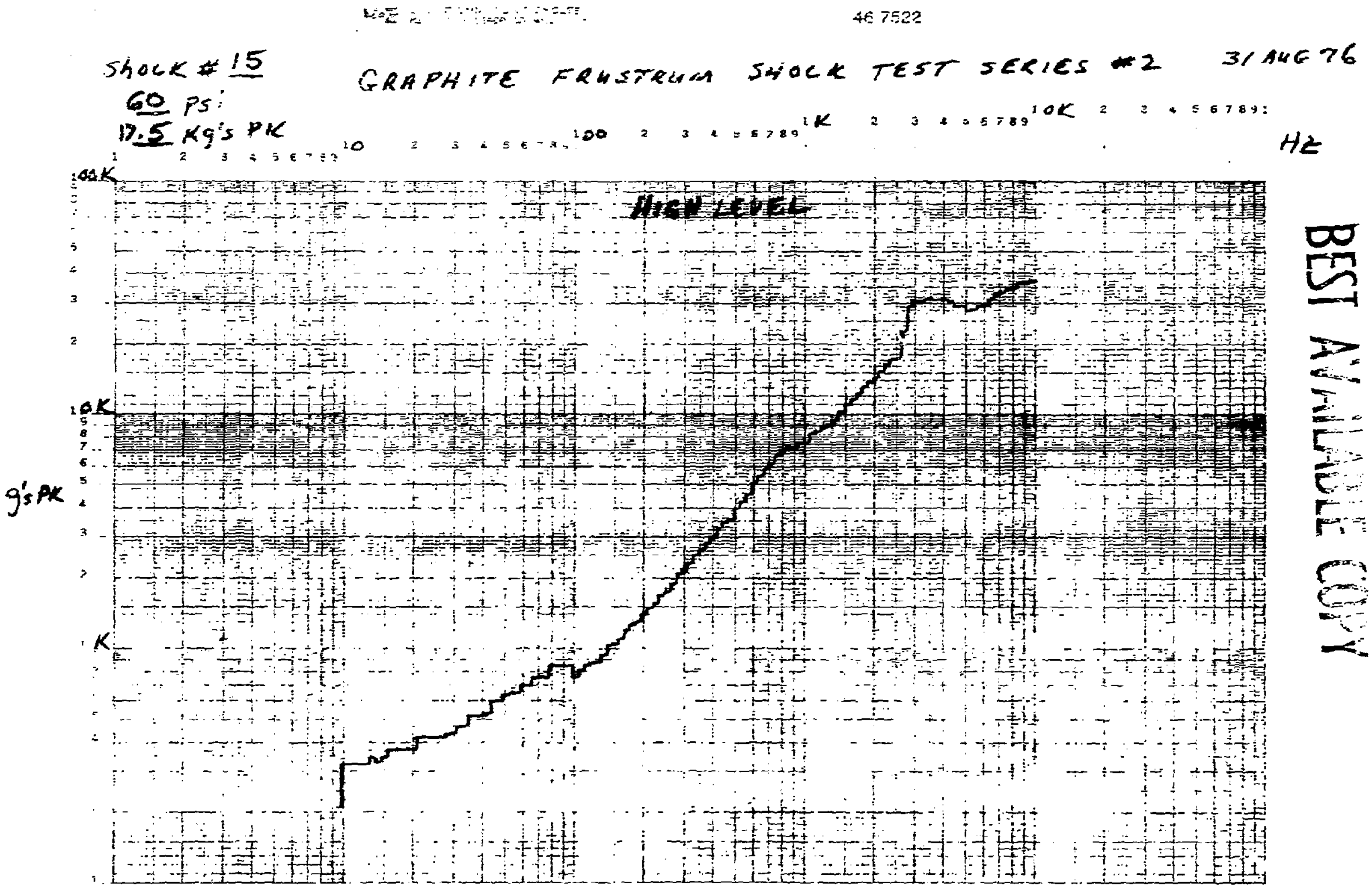
31 AUG 76




SHOCK #L3 GRAPHITE FRUSTRUM SHOCK TEST SERIES #2 31 AUG 76
60 PSI
125 Kg's PK
HZ
III LEVEL
g_c' PK
1
10
100
1K
10K

BEST AVAILABLE COPY





46 7522
SHOCK # 15
60 PSI
17.5 Kg's PK
GRAPHITE FRUSTRUM SHOCK TEST SERIES #2
31 AUG 76
HIGH LEVEL
g's PK
Hz
10
100
1K
10K

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